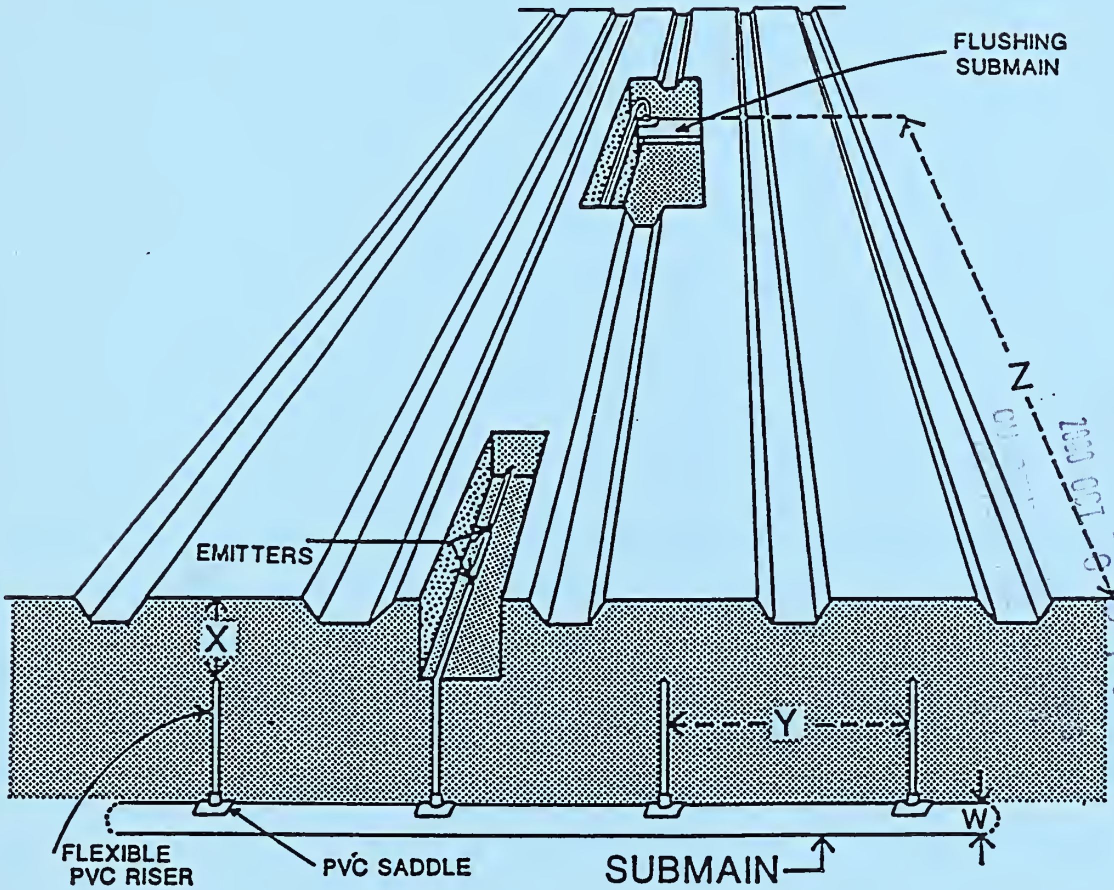
United States
Department of
Agriculture

Agricultual
Research
Service



WATER MANAGEMENT RESEARCH LABORATORY

PROGRESS REPORT 1992

This 1992 Progress Report is dedicated to Dr. Claude J. Phene for his 30 years of Government service. Claude's knowledge and guidance have been a valuable part of the growth and stature of the Water Management Research Laboratory since 1978.

ANNUAL PROGRESS REPORT

1992

Water Management Research Laboratory
Agriculture Research Service
U.S. Department of Agriculture
2021 South Peach Avenue
Fresno, California 93727

Telephone: (209) 453-3100
Facsimile: (209) 453-3122

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

INTRODUCTION

The Water Management Research Laboratory Research Progress Report is intended to inform upper level management within the Agricultural Research Service, other ARS research locations involved in natural resources research, and our many collaborators and cooperators about progress made on our research projects in 1992 and plans for 1993. It is our intent to keep the individual reports short but informative, focusing on objectives, approaches, summarized results and future plans for the project.

The overall mission of the Water Management Research Laboratory is to conduct research and to develop advanced water management practices, methods, equipment, and systems to utilize soil, water, nutrients, and energy resources efficiently and to improve sustainability and crop productivity in irrigated agriculture under water–limited conditions.

The Laboratory, in cooperation with personnel at the U.S. Salinity Lab in Riverside, CA, the U.S. Cotton Research Station at Shafter, CA, and the University of California, Riverside and Davis, CA, has initiated several new CRIS research projects and is addressing specifically the issues of the impact of limited water supplies and drainage on water quality, water use efficiency, sustainability and productivity of Western irrigated agriculture. Cooperative projects are funded by the California Department of Water Resources (DWR) and the State Water Resource Control Board, the Imperial Irrigation District (IID, the Metropolitan Water District (MWD) of Southern California and the Imperial Valley Conservation Research Center Committee (IVCRCC).

We invite you to use this annual report and to forward your questions and comments to us at your convenience; they will be appreciated. We thank you for your support and interest.

CLAUDE J. PHENE
Research Leader

MANAGEMENT RESEARCH LABORATORY STAFF

I. Federal Employees	Position
1. Scientists	
Phene, Claude	Research Leader, Soil Sci.
Ayars, James	Agricultural Engineer
Hutmacher, Robert	Plant Physiologist
Banuelos, Gary	Plant/Soil Scientist
Avishalom Marani	Visiting Scientist, Israel
Ben-Asher, Jiftah	Visiting Scientist, Israel
Cardon, Grant	Soil Physicist
2. Technical Support/Full Time	
Clark, David	Electronics Engineer
Dale, Frank	Hydrologic Technician
Davis, Kenneth	Soil Scientist
Dettinger, David	Machinist
Mead, Richard	Biological Technician, Soils
Pflaum, Tom	Chemist
Schoneman, Richard	Agricultural Engineer
Vail, Sue	Biological Technician, Plants
Zambrzuski, Stella	Biological Technician, Plants

Technical Support/Temporary Part Time	Position
Ament, Colleen	Biological Technician
Beta, Meso	Biological Technician, Plants
Bravo, Andy	Biological Technician
Downey, Steve	Biological Technician, Plants
Ehn, Erik	Bilogical Technician
Grasser, Angela	Bilogical Technician
Hagans, Bruce	Laboratory Technician
Hawks, Carl	Biological Technician, Plants
Horder, Che	Biological Technician
Jones, Matthew	Electronics Technician
Marhenke, Jon	Biological Technician
Misaki, Jeff	Biological Technician
Morris, Sarah	Laboratory Technician
Murphy, Kathleen	Biological Technician

MANAGEMENT RESEARCH LABORATORY STAFF (CONT'D)

Technical Support/Temporary Part Time	Position
Nevarez, Arthur	Biological Technician
Nguyen, Hung	Biological Technician
Osterberg, Linnea	Biological Technician
Penland, Jason	Biological Technician
Peters, Merle	Biological Technician, Plants
Piyasil, Fawn	Biological Technician
Pranger-Chin, Winnett	Laboratory Technician
Rains, Stacia	Biological Technician
Samra, Parmijit	Biological Technician
Trent, Jessica	Biological Technician
Wong, Frank	Biological Technician
Yang, Eng	Biological Technician
Yue, Ronggui	Biological Technician

3. **Administrative Support**

Karen Nichols	Secretary
Sherry Delto	Automation Clerk

II. Part-Time Student Assistants

1. **Research Support Agreement (Fresno State University Foundation)**

Name	Position	Supervisor
Akohoue, Sylvie	Laboratory Technician	G. Banuelos
Hinds, Fay	Laboratory Technician	T. Pflaum
Lockner, Thierry	Electronics Technician	C. Phene
Norman, Maurice	Electronics Technician	C. Phene
Polous, Tony	Electronics Technician	C. Phene

WATER MANAGEMENT RESEARCH LABORATORY COLLABORATORS

Collaborator	Affiliation
Abrahamson, S.L.	USDA/ARS Area Office, Albany, CA
Ballard, D.	US Cotton Research Station, Shafter, CA
Belcher, H.W.	Michigan State University, East Lansing MI
Ben–Asher, J.	Ben Gurion University, Israel
Beuselinck, P.	USDA/ARS, University of Missouri, Columbia, Mo
Biggar, J.	University of California, LAWR Dept., Davis, CA
Biscay, P.	Kearney Agricultural Center, Parlier, CA
Brown, P.	University of California, Dept. of Pomology, Davis, CA
Currie, D.	Elmore Farms, Imperial, CA
El–Bershamgy, A.	Agricultural Research Ctr., Giza, Egypt
El–Mowelhi, N.	Agricultural Research Ctr., Giza, Egypt
Falaschi, D.	Panoche Water District, Firebaugh, CA
Fernandez, T.	Boyle Engineering, Inc., Fresno, CA
Fouss, J.L.	USDA/ARS, Baton Rouge, LA
Grimes, D.W.	Kearney Agricultural Center, Parlier, CA
Howell, T.A.	USDA/ARS, Bushland, Texas
Hu, H.	University of California, Davis, CA
Hudson, N.	US Cotton Research Station, Shafter, CA
Itier, B.	INRA, Thiverval – Grignon, France
Jobes, J.	USDA/ARS, Salinity Lab., Riverside, CA
Johnson, R.S.	Kearney Agricultural Center, Parlier, CA
Keeley, P.	US Cotton Research Station, Shafter, CA
Kerby, T.	UC Cooperative Extension, Shafter, CA
Kershaw, R.	Imperial Valley Conservation Research Center Committee, Brawley, CA
Mackey, B.E.	USDA/ARS Area Office, Albany, CA
O'Halloran, T.	Imperial Irrigation District, Imperial, CA
Ow, D.W.	USDA/ARS Area Office, Albany, CA
Perry, R.	USDA/ARS Salinas, CA
Peters, D.	University of California, Davis, CA
Rhoades, J.D.	USDA/ARS Salinity Lab., Riverside, CA
Rolston, D.E.	University of California, Davis, CA
Schneider, A.D.	USDA/ARS, Bushland, Texas
Shackel, K.	University of California, Pomology Dept., Davis, CA
Shouse, P.	USDA/ARS Salinity Lab., Riverside, CA

WATER MANAGEMENT RESEARCH LABORATORY COLLABORATORS (CONT'D)

Collaborator	Affiliation
Silva, J.	Imperial Irrigation District, Imperial, CA
Solomon, K.R.	California State University, Fresno, CA
Speiser, D.M.	USDA/ARS Area Office, Albany, CA
van Genuchten, M.	US Salinity Lab., Riverside, CA
van Schilfgaarde, J.	USDA/ARS Area Office, Ft. Collins, CO
Watson, C.	University of Arizona, Tucson, AZ
Wiley, P.	Kearney Agricultural Center, Parlier, CA
Williams, L.	Kearney Agricultural Center, Parlier, CA
Wu, L.	University of California, Davis, CA
Zick, M.	Cedar Chemical Co., Fresno, CA

LOAD–FLOW RELATIONSHIPS IN PANOCHE WATER AND DRAINAGE DISTRICT I. DISTRICT RELATIONSHIP

J.E. Ayars and R.A. Schoneman

OBJECTIVES: Characterize the load–flow relationship for salt discharge at the main drain from the Panoche Water and Drainage District (PWDD).

PROCEDURES: Monthly values of drain flow, electrical conductivity, total dissolved solids and concentrations of boron and selenium were measured at the main drain from the PWDD. The concentration of salts and flow were used to calculate the load from the district. This load was used in a regression with the corresponding flow to determine the load–flow relationship from the district.

RESULTS: The regression relationship for the district was found to be linear. This relationship is shown in Figure 1 along with a relationship which was developed using only flow less than 4 million m^3 per month. The linear relationship for the entire flow in Figure 1 is a good statistical fit, however at flow greater than 4 million m^3 per month the load is diverging way from the line. In Figure 4 B the higher flows have been removed and the slope of the line has increased suggesting that the higher flows have been diluting the flow from the district. The months with the highest drain flows have been in the summer which is also the time of highest water deliveries. Runoff from surface irrigation during the summer has probably been the source of dilution water to the drain flow. As the water supply decrease due to the drought and with improved irrigation practices there has been less water in the drain. This point was discussed in the 1991 annual report.

FUTURE PLANS: A manuscript has been prepared describing the results of this study.

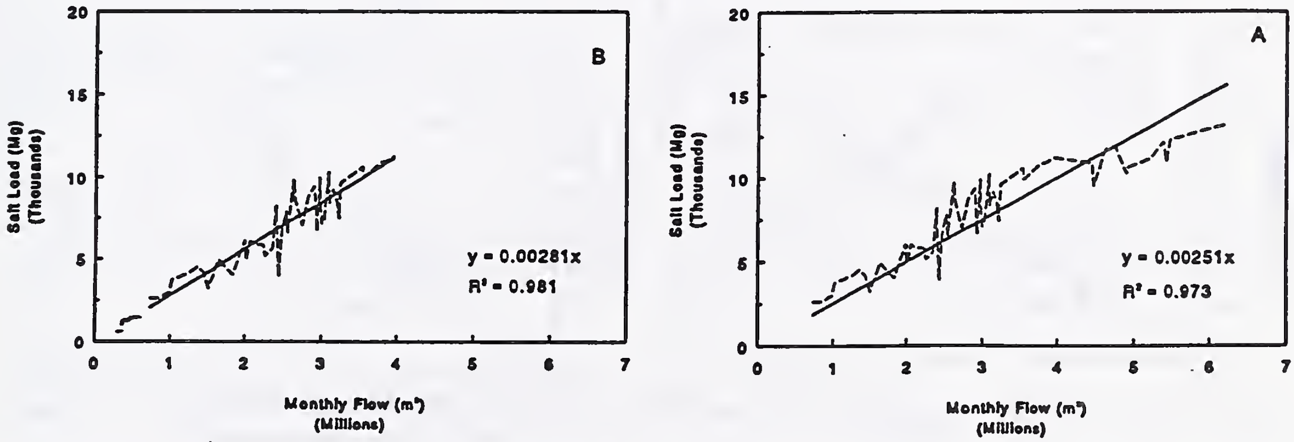


Figure 1. Load–flow relationship for salt discharge from the Panoche Water and Drainage District for all flows (A) and for flow less than 4 million m^3 per month (B).

LOAD-FLOW RELATIONSHIPS IN PANOCHE WATER AND DRAINAGE DISTRICT II. DRAINAGE SUMP RELATIONSHIP

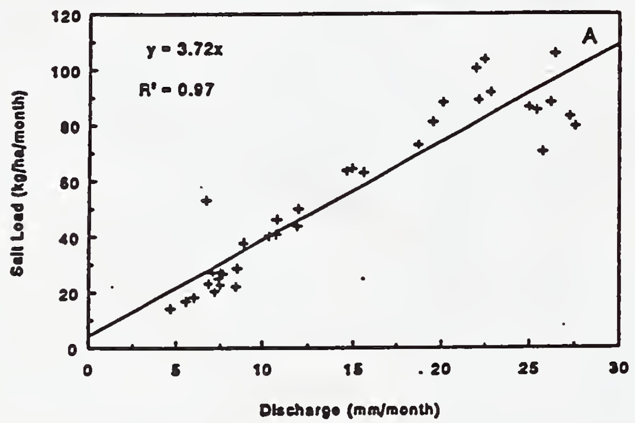
J.E. Ayars and R.A. Schoneman

OBJECTIVES: Determine the load-flow relationship for drainage discharge from individual drainage sumps located in the Panoche Water and Drainage District (PWDD).

PROCEDURES: Monthly readings were made of the discharge from individual drainage sumps throughout the PWDD by PWDD personnel. Water samples were taken at the time of measurement and these samples were analyzed for electrical conductivity, boron and selenium concentrations, and total dissolved solids. The monthly load was calculated based the area drained. The load was correlated to the monthly discharge computed as a depth per unit area.

RESULTS: Representative regressions are shown for two drainage sumps in Figure 1. A linear regression was found to fit the relationship in both cases. This is true for the remain 43 drainage sumps which were analyzed. The slope of the regression lines indicated that there was a significant difference in the concentration of the effluent leaving the sump. The discharge from DP2 (A) was distributed evenly from 0 to 30 mm/month while the flow from DP8(B) is clustered from 40 to 60 mm/month with a few values above and below. Despite the higher flow in DP8 the load range is approximately the same as found in DP2. Further statistical analysis of the regressions from each sump indicated that all of the load-flow relationships could be clustered into 3 relationships.

FUTURE PLANS: A manuscript has been prepared which discusses these results.



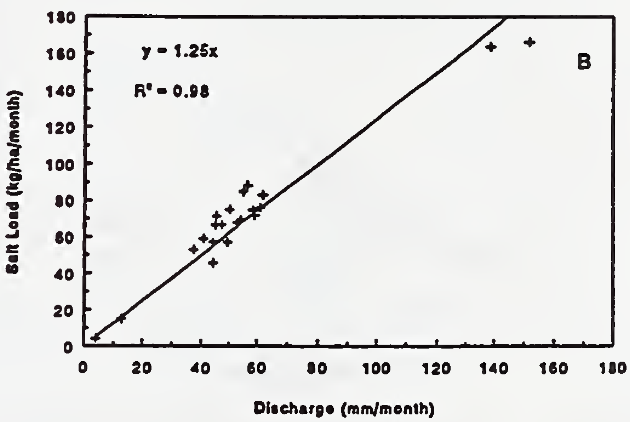


Figure 1. Load-flow data for salt in drainage water from drainage point DP2(A) and drainage point DP8(B) in the Panoche Water and Drainage District.

LOAD-FLOW RELATIONSHIPS IN PANOCHE WATER AND DRAINAGE DISTRICT III. FIELD RELATIONSHIPS

J.E. Ayars and R.A. Schoneman

OBJECTIVES: Determine the load-flow relationship for drainage discharge from an individual field drain.

PROCEDURES: Two fields which were being used in an irrigation efficiency study were instrumented with water meters at the outlet of the field. These water meters were read weekly. Water samples were taken at the time the meters were read. Water quality was analyzed for all the major cations and anions as well as boron and selenium. The load was calculated on a unit area basis. The load was correlated to the unit flow calculated as a daily value from the weekly values. Statistical regression was used to characterize the result.

RESULTS: The load-flow relationships for salt for two field sites are given in figure 1 A and B. A linear relationship was found to give a good statistical representation of the data. The data points fall very close to the regression line in this case while there is more scatter about the relationship developed for the monthly flows from the drainage points and the main drain. There is an order of magnitude difference in the discharge and load from these two sites. This is indicative of the variability that can be found throughout this region.

FUTURE PLANS: These results have been include in a manuscript.

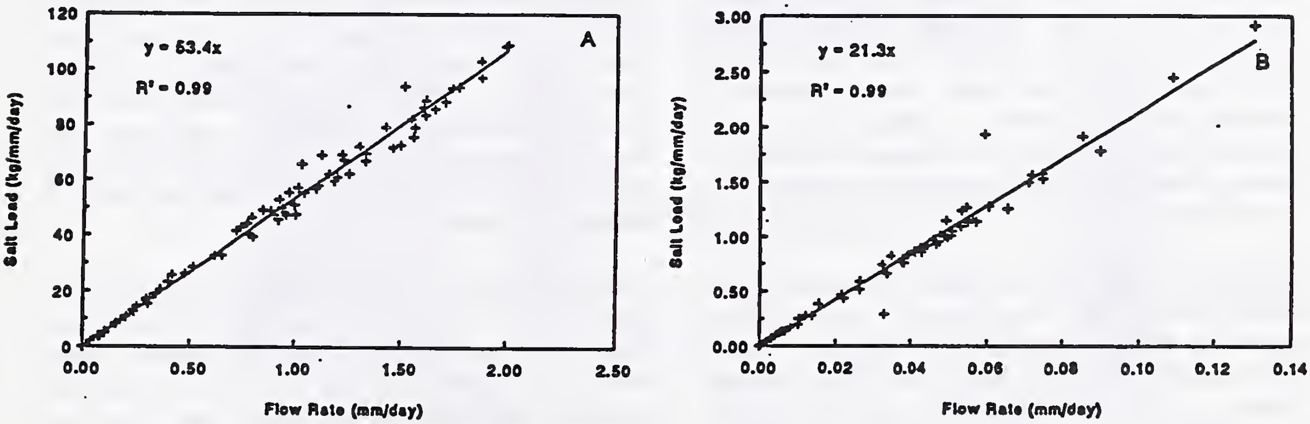


Figure 1. Load-flow data for salt in drainage water from field site A2(A) and B2(B) in the Panoche Water and Drainage District.

FIELD UNIFORMITY EVALUATION OF DRIP IRRIGATION SYSTEMS-OVERVIEW

C. J. Phene, I-Pai Wu, R. Yue, L. Kong, J. Ayars
R. Schoneman, K. Davis, R. Mead, B. Meso

OBJECTIVES: To summarize the field uniformity evaluation results of both surface and subsurface drip irrigation systems. The objective of evaluating drip irrigation systems is to insure that water, fertilizers and chemicals are supplied both uniformly and efficiently.

PROCEDURES: Three uniformity parameters: uniformity coefficient, UC; emitter flow variation, q_{var}; and coefficient of variation, CV, were used to express the evaluation results. The evaluation covers seven types of drip irrigation systems at four locations: T-Tape, Typhoon, Chapin, Roberts, Ram, at 30 Acres of this Laboratory and Britz Farm, Mendota, CA; Agrifim In-Line turbulent flow emitters at UC West Side Field Station (WSFS); and RootGuard at USDA Irrigated Desert Research Station, Brawley, CA. The major method involved is Random-18-Point method. The surface drip systems at 30AC have also been evaluated by Uniform-45-Point method. Please refer to the separate reports in this Annual Report for detail test results, or earlier Annual Report for information on those systems.

RESULTS: Figure A through F shows the evaluation results on the seven types of drip irrigation systems at the four locations, with Figures A and B for UC, Figures C and D for CV, and Figures E and F for q_{var}. The tested UC ranges from 76% to 97%, CV from 3% to 35%, and q_{var} from 9% to 100%.

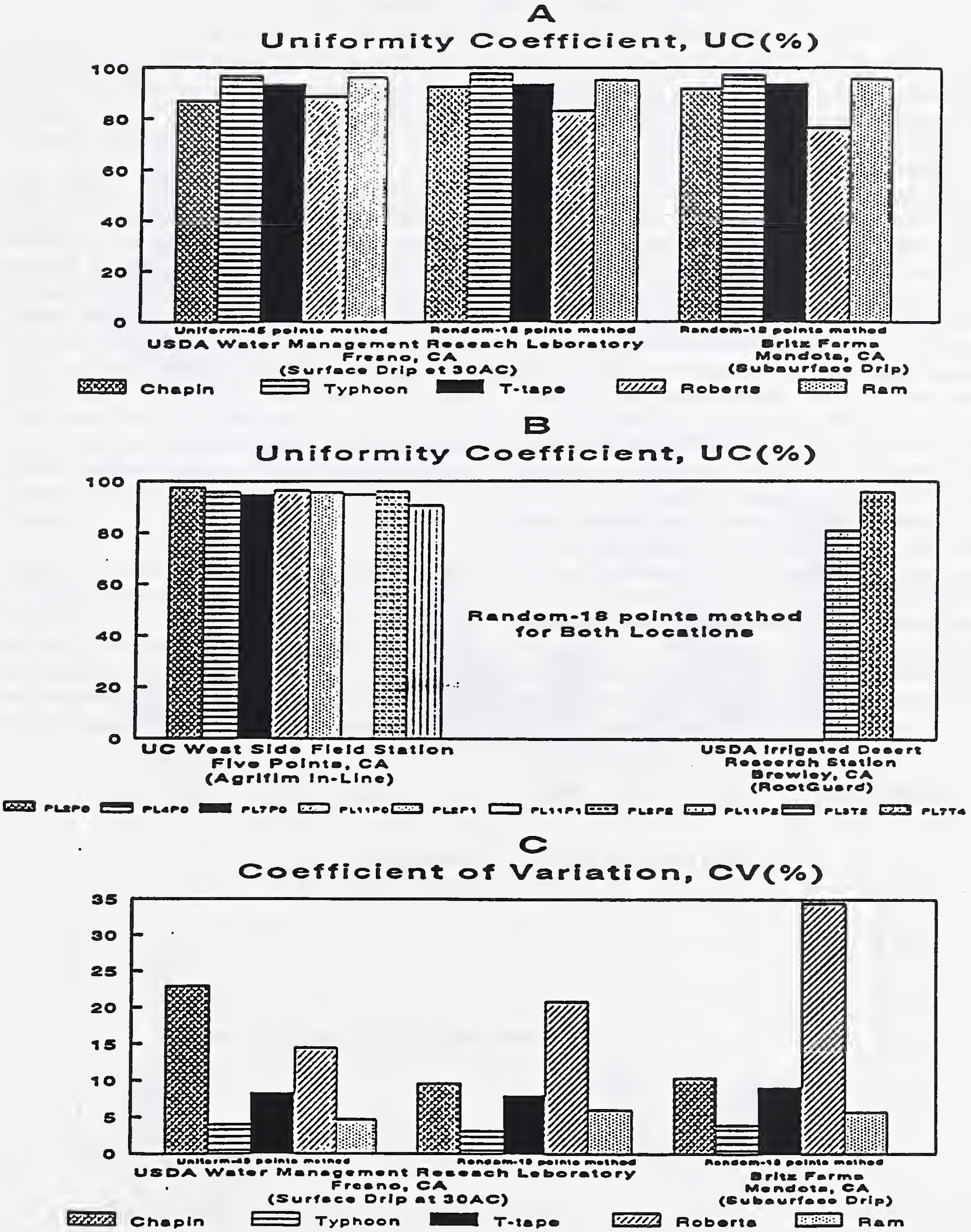
Hydraulic design is one of the main factors that may affect drip irrigation system uniformity. The main items involved in the hydraulic design are type of emitter, size and type of tubes and\or pipes, field layout, field slope, and the scale of the drip irrigation system.

There are more factors that may affect drip irrigation system uniformity significantly, such as unrepaired tube and\or pipe leaks, emitter plugging, emitter manufacturing variation, and temperature etc. That is why different UC or CV or q_{var} is obtained even for the drip systems with the exact same hydraulic design such as the Agrifim In-Line subsurface drip treatments P0s or P1s or P2s at West Side Field Station. When emitter manufacturing variation and\or emitter plugging, either or both partial and total plugging, must be considered in evaluating drip irrigation systems, q_{var} will no longer be a suitable uniformity parameter.

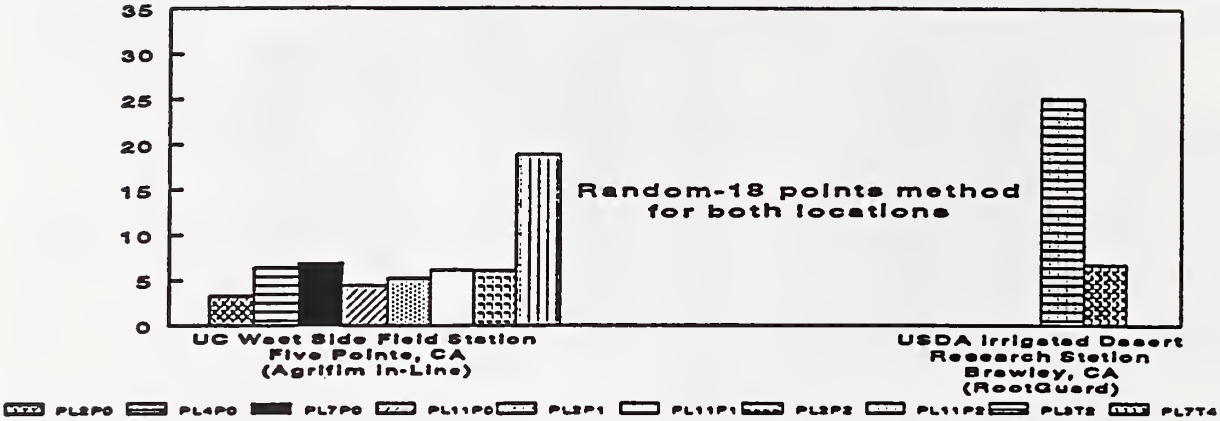
The evaluation results of Random-18-Points method did not always match the ones of Uniform-45-Points method based on the tests results on surface drip systems. The values of UC, CV and q_{var} obtained by Random-18-Points method for Typhoon, T-Tape and Ram surface drip systems matched the ones obtained by Uniform-45-Points method very well. On the other hand, the ones obtained by Random-18-points method for Chapin and Roberts surface drip systems does not match the ones obtained by Uniform-45-Points method. In term of UC, the difference is about 6%. It is noted that no water flowed out of the emitters along the two sections of the Chapin tubes used for this test, and that there were a lot of very small leaks along the Roberts tubes tested. However, it can not be sure that plugging and leaking are the main reasons for the large differences in terms of UC, CV and q_{var} between the two test methods on the two kinds of surface drip systems.

Emitter plugging did exist in some of the tested drip systems. Two out of the 20 emitters exposed in the Roberts subsurface drip treatment at Britz Farm were found to be totally plugged. No total emitter plugging was found in the other four kinds of subsurface drip irrigation treatments there. As for the Agrifim In-Line subsurface drip systems at West Side Field Station, both Plot 11, P0 and Plot 11, P1 had one emitter totally plugged. Plot 7, Treatment 4, of the RootGuard subsurface drip systems at USDA Irrigated Desert Research Station, Brawley, CA, had a very high uniformity coefficient of 95.77%. However, Plot 3, Treatment 2 had a measured UC as low as 80.95%. The emitter flow rate data recorded there showed that three out of eighteen emitters exposed in Plot 3, Treatment 2, were partially plugged.

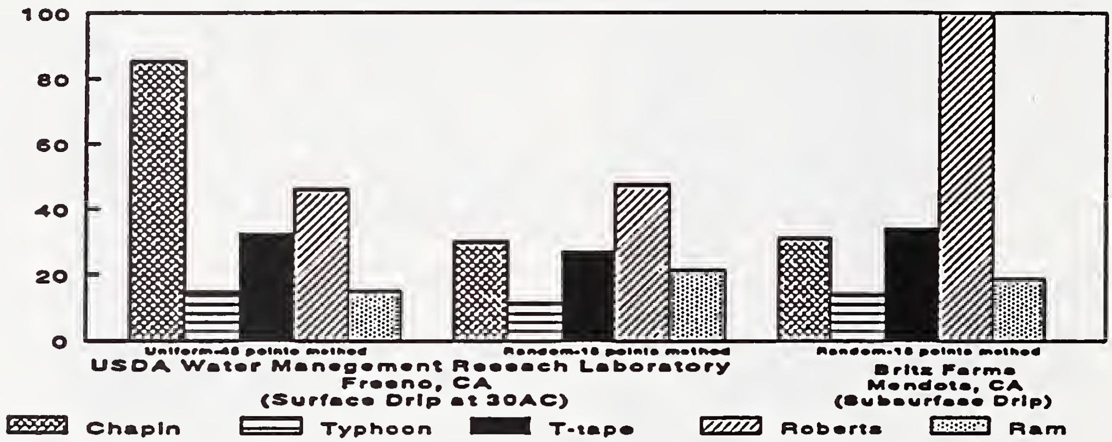
The water samples taken at the end of the submains after the tests in Brawley contained alfalfa tissues. Several leaks were found inside the subsurface drip treatments again later during the tests and were not repaired due to the limited time. Those unrepaired leaks affected the emitter discharge uniformity.


A
Uniformity Coefficient, UC(%)
100
80
60
40
20
0
Uniform-45 points method
Random-18 points method
Random-18 points method
USDA Water Management Reseach Laboratory
Fresno, CA
(Surface Drip at 30AC)
Britz Farms
Mendota, CA
(Subsurface Drip)
Chapin
Typhoon
T-tape
Roberts
Ram
B
Uniformity Coefficient, UC(%)
100
80
60
40
20
0
Random-18 points method
for Both Locations
UC West Side Field Station
Five Points, CA
(Agrifim In-Line)
USDA Irrigated Desert
Research Station
Brawley, CA
(RootGuard)
PL2P0
PL4P0
PL7P0
PL11P0
PL2P1
PL11P1
PL2P2
PL11P2
PL3T2
PL7T4
C
Coefficient of Variation, CV(%)
35
30
25
20
15
10
5
0
Uniform-45 points method
Random-18 points method
Random-18 points method
USDA Water Management Reseach Laboratory
Fresno, CA
(Surface Drip at 30AC)
Britz Farms
Mendota, CA
(Subsurface Drip)
Chapin
Typhoon
T-tape
Roberts
Ram

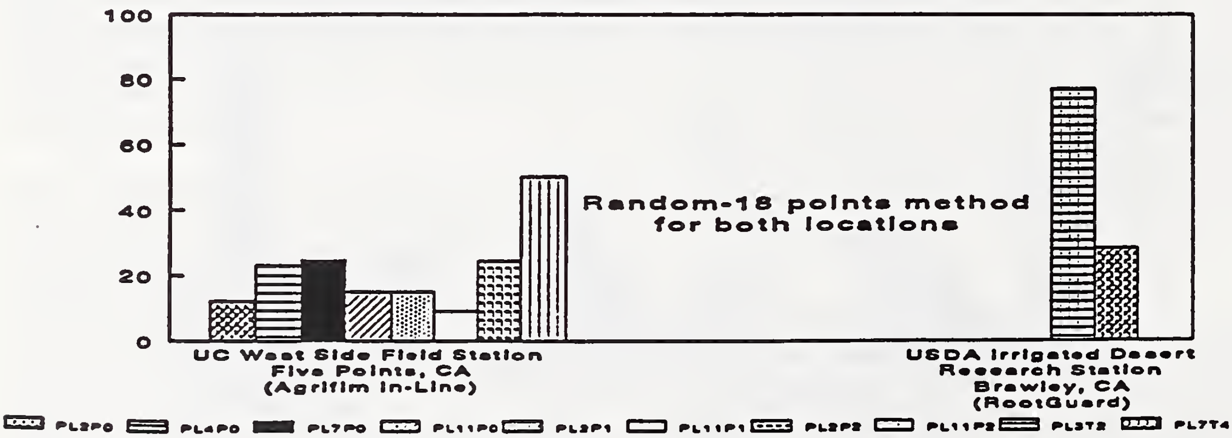
D
Coefficient of Variation, CV(%)



E
Emitter Flow Variation, q_{var}(%)



F
Emitter Flow Variation, q_{var}(%)



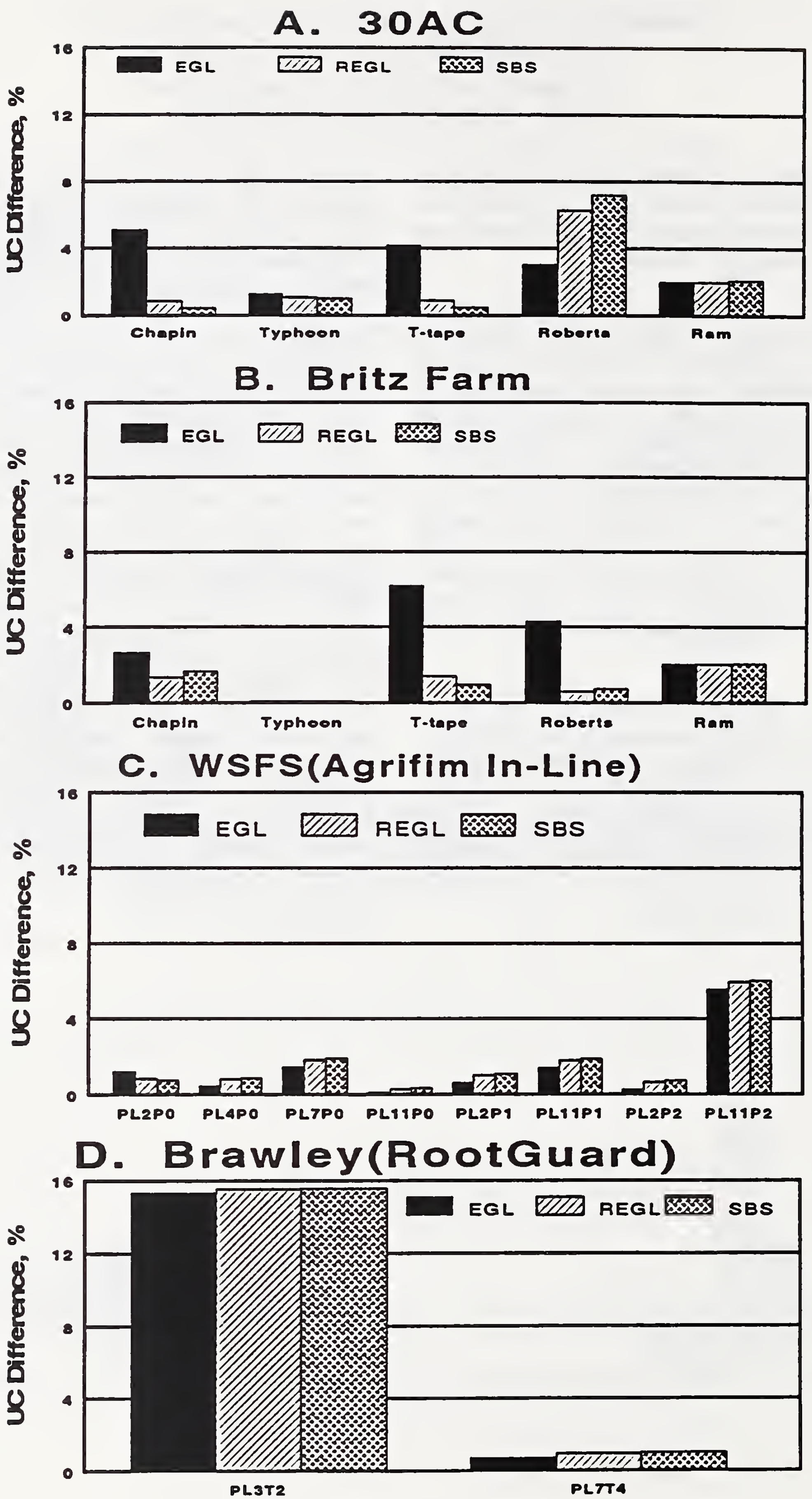
VALIDATION OF DRIP IRRIGATION SYSTEM DESIGN AND EVALUATION MODELS WITH FIELD DATA

C. J. Phene, I-Pai Wu, R. Yue, L. Kong, J. Ayars
R. Schoneman, K. Davis, R. Mead, B. Meso

OBJECTIVES: To validate computerized drip irrigation system design and/or evaluation models with field test results on several existing subsurface drip irrigation systems in California.

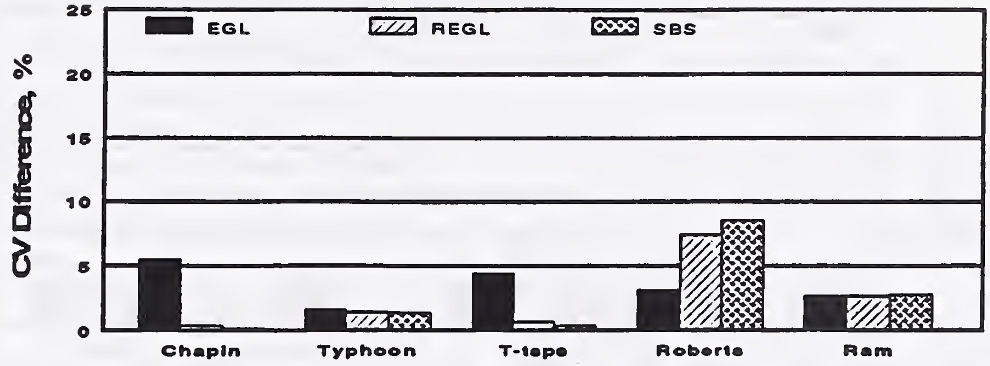
METHODS: The significant advantage of computerized evaluation of drip irrigation systems is eliminating the excessive physical work for sampling emitter flow rates and exposing emitters if the system is buried. All the drip systems described in "Field Uniformity Evaluation of Drip Irrigation Systems-Overview" of this Report were simulated with computer program CEDDIS Version 5.5. The simulation results by EGL, REGL and SBS models were compared with the field test results. For information on CEDDIS Version 5.5, or the three models, please refer to, "Drip Irrigation System Design and Evaluation Computer Program", in this Report.

RESULTS: Figures A through L show the differences between model simulation results and field test results for the seven types of drip irrigation systems at four locations. Generally, the UC or CV difference between model simulation results and field test results are less than 3% for REGL and SBS model, and less than 8% for EGL model. In most cases, the model simulation results are in good agreement with each other and with the ones of field tests, the REGL and SBS give similar results, and the results of both REGL and SBS match the ones of field tests better than the ones of EGL model. In term of q_{var}, the differences between model simulation results and field test results may exceed 5%, no matter which model is used. The main reason is that q_{var} might not be a suitable uniformity parameter if any of the following needs to be considered: emitter manufacturing variation, emitter plugging, and leaks. They are the main reasons for very large differences between model simulation results, no matter which model is used, and field test results, in some cases such as in Plot 3, Treatment 2 at Brawley. All three models in CEDDIS Version 5.5, i.e., EGL, REGL and SBS, are programmed to include manufacturing variation and emitter plugging, both partial and total, in their hydraulic simulations. Unfortunately, for the subsurface drip systems buried 45 cm deep, it is very difficult to get the exact percentage of the emitters totally plugged, and\or the percentage of emitters partially plugged and in what degree they are plugged. Moreover, there might be leaks, especially the ones along thin-wall tubes, which are unrecognized and are not repaired before measuring the emitter discharge rates.

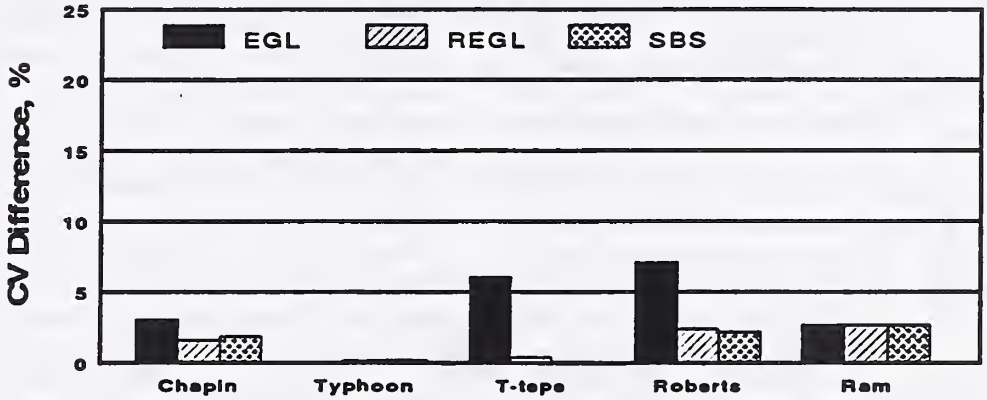


Tube length: 160 m; Tube type: RootGuard; x - 0.5400

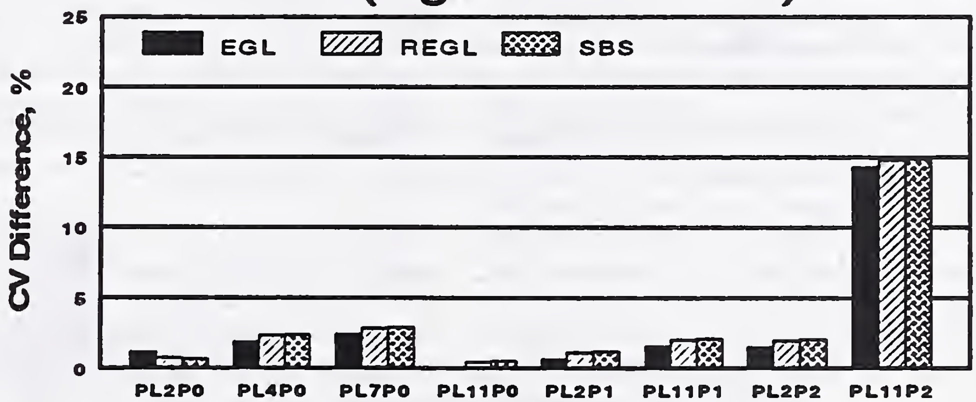
E. 30AC



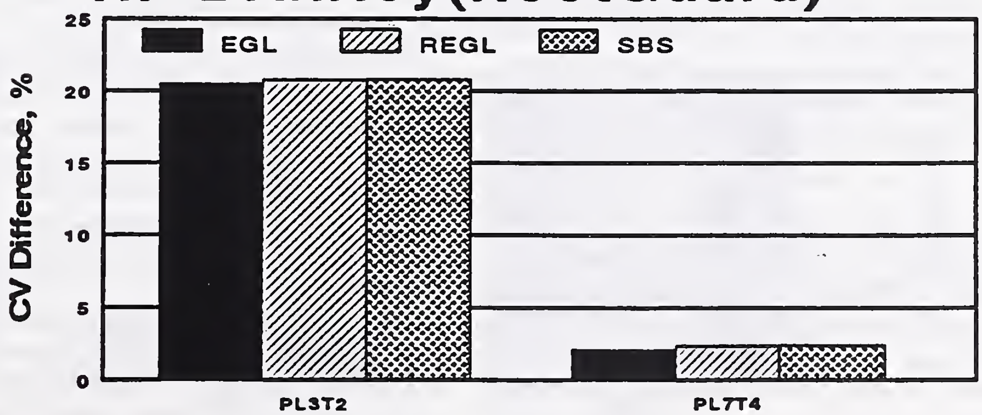
F. Britz Farm

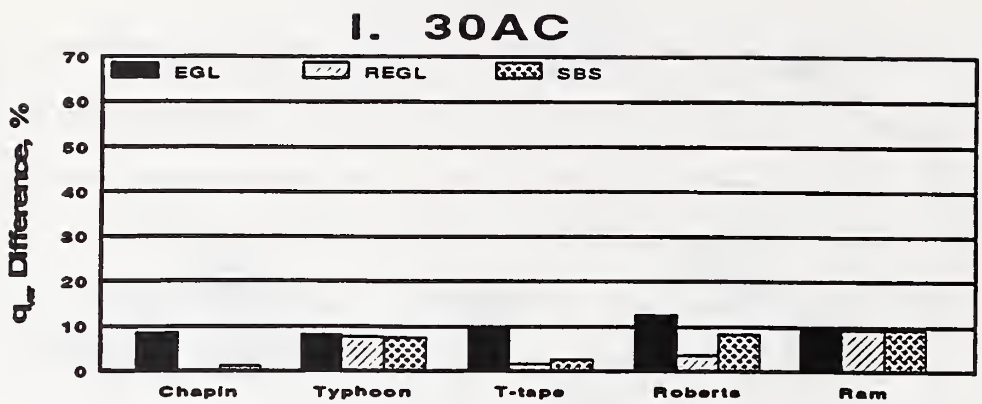


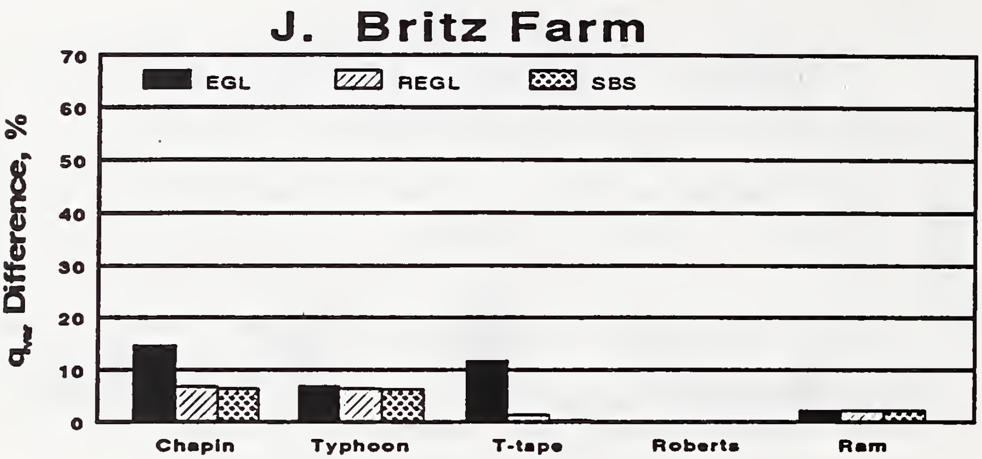
G. WSFS(Agrifim In-Line)

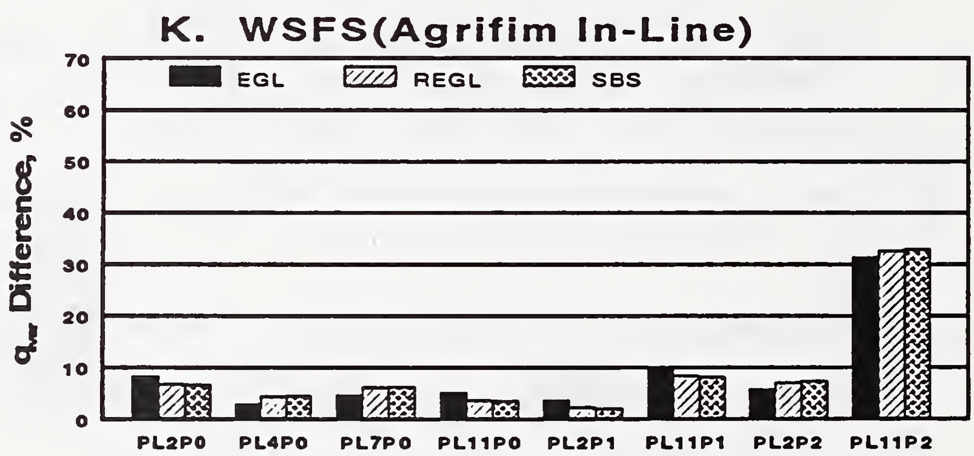


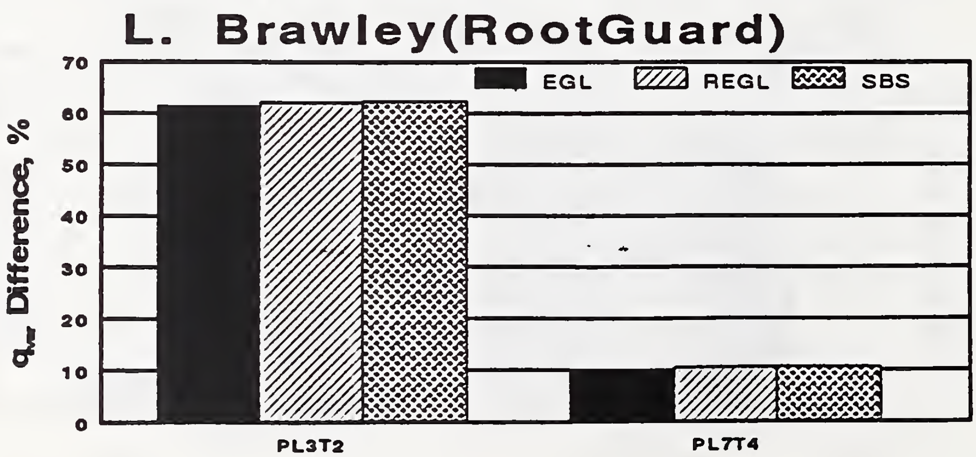
H. Brawley(RootGuard)




I. 30AC
EGL
REGL
SBS
q_{var} Difference, %
0
10
20
30
40
50
60
70
Chapin
Typhoon
T-tape
Roberts
Ram


J. Britz Farm
EGL
REGL
SBS
q_{var} Difference, %
0
10
20
30
40
50
60
70
Chapin
Typhoon
T-tape
Roberts
Ram


K. WSFS(Agrifim In-Line)
EGL
REGL
SBS
q_{var} Difference, %
0
10
20
30
40
50
60
70
PL2P0
PL4P0
PL7P0
PL11P0
PL2P1
PL11P1
PL2P2
PL11P2


L. Brawley(RootGuard)
EGL
REGL
SBS
q_{var} Difference, %
0
10
20
30
40
50
60
70
PL3T2
PL7T4

A USER FRIENDLY MICROCOMPUTER PROGRAM FOR DRIP IRRIGATION SYSTEM DESIGN AND EVALUATION

R. Yue, C. J. Phene, J.E. Ayars, I-Pai Wu, L. Kong

OBJECTIVES: To supply a simple, user friendly microcomputer program, Comprehensive Evaluation and Design of Drip Irrigation Systems Version 6.0, which can be used to design and evaluate drip irrigation systems.

METHODS: For densely-planted crops with both crop spacing and row spacing shorter than emitter spacing, distribution uniformity of irrigated water depth in crop root zone soil, named as SPatial Uniformity Coefficient of irrigation depth, will be a better parameter to express water application uniformity by a drip irrigation system than system uniformity parameters UC, CV and q_{var} of emitter flows. Besides disturbing crop root zone soil and damaging crops, field measurement of SPUC involves a lot of physical work in taking soil samples and measuring soil water contents. CEDDIS Version 6.0 is developed to simulate the SPUC of drip irrigation systems. The program is developed in Turbo Pascal Version 6.0, based on CEDDIS Version 5.5 and SUBmain SPatial Uniformity of Coefficient, a program developed to simulate SPUC of submain units by assuming that emitter spacing and lateral spacing can be expressed as ratios of nominal emitter wetting width. For details on CEDDIS Version 5.5, please see "Drip Irrigation System Design and Evaluation Computer Program", in this report. CEDDIS Version 6.0 can be run on IBM compatible personal computers.

RESULTS: CEDDIS Version 6.0 uses the REGL model in CEDDIS 5.5 to perform the system hydraulic design. The reason for selecting REGL model is that REGL model possesses the accuracy of SBS model and the speed of EGL model. EGL model is the simplest, but not as accurate as either REGL or SBS. SBS model is the most accurate one, but is also the most tedious one.

SPUC is calculated from the irrigation depth profile of the submain unit, which is expressed by the accumulated water depths at finite number of nodes inside the submain unit. The number of nodes is determined by the distance between the adjacent node lines and the size of the submain unit. All the nodes is uniformly distributed over the area covered by the submain unit. To perform a reliable design or evaluation, there should be at less 5 nodes between each two adjacent emitters. The irrigated water depth at each node is calculated by super-positioning the irrigated water depths from all the surrounding emitters. A filter is developed to pick up only those emitters the water from which will reach that particular node. The Emitter wetting pattern is assumed as either half a cone or half an ellipsoid. The size of wetting body of each emitter depends on its discharge rate. A nominal size, expressed by wetting width and wetting depth, is input for the assumed nominal emitter that has a discharge rate equal to the average emitter discharge of the submain unit. The wetting width and wetting depth of the nominal emitter depend on the discharge rate, irrigation time, and soil characteristics such as hydraulic conductivity, initial soil water content, saturated soil water content etc.

CEDDIS 6.0 can be used to design and/or evaluate any sizes of drip irrigation submain units as long as no negative pressure occurs inside the pipe systems. In case of zero lateral slope, the laterals may lay on either one or two sides of the submains. Emitter pressure profile, emitter discharge profile and irrigation depth profile will be automatically saved into data files PRESSURE, DISCHARGE and DEPTH respectively. They can also be saved into whatever files named by the users. The maximum, minimum and average values of emitter pressures, emitter discharge rates and irrigation depths will be shown in the Output menu as shown in figure 2. To keep the continuity of CEDDIS program series and to make future revision on CEDDIS easier, those parameters and files which appears in the old version and are still required in this new version are kept unchanged. All the new parameters and files are named as the original or shorthand of the subject terms in drip irrigation area. Data input and output are in the same way and format as the old versions as shown in figure 1 and 2.

CEDDIS 6.0 is an user friendly program. By simply following the step-by-step instructions, user can easily evaluate or design a drip irrigation submain unit. The on-line Help program supply users with useful information besides defining the definitions for all the parameters.

CEDDIS Version 6.0 will create four temporary data files at the beginning of its operation, and from then on will continue to communicate with them. As the last step of its operation, all the four temporary data files will be automatically erased and the Output menu will come on screen to show the simulation or design results.

FUTURE PLAN: The accuracy of model simulations on UC, CV and q_{var} has been evaluated as described in, "Validation of Drip Irrigation System Design and Evaluation Models with Field Data", of this annual report. Model simulations on SPUC need to be evaluated. CEDDIS 6.0 can be expended to including drip irrigation system cost evaluation. The following improvement will make CEDDIS 6.0 more reasonable, practical and accurate: using soil characteristics, irrigation time and emitter discharge rate profile to express the irrigation depth profile, then calculating water distribution profile by overlapping the initial water inside the crop root zone soil.

INPUT MENU

CEDDIS 6.0

SUBMAIN		LATERAL		EMITTERS	
Pressure(Kpa) =	110.00	Spacing(m) =	1.50	Spacing(m) =	1.50
Length(m) =	30.00	Length(m) =	150.00	WetWidth(m) =	2.00
Diameter(cm) =	3.000	Diameter(cm) =	1.600	WetDepth(m) =	0.75
Constant K =	1.6E+0005	Constant K =	1.6E+0005	Constant k =	0.4500
Friction C =	150	Friction C =	150	Exponent x =	0.5000
Exponent M =	1.8520	Exponent M =	1.8520	ManuCv(%) =	10.00
Slope(%) =	0.00	Slope(%) =	0.00	Total Plug(%) =	5.00
D-nodes(m) =	0.20	P-Degree(%) =	50.00	P-Percent(%) =	5.00

** Press HELP for the definitions of the parameters

Use the arrow keys to move the cursor.

Use the function keys to perform the analysis.

F1-Help F2-Analysis F3-Switch Unit Esc-Exit

Figure 1.

CEDDIS 6.0

OUTPUT MENU

****** GIVEN INFORMATION ******

SUBMAIN		LATERAL		EMITTERS	
Pressure(Kpa) =	110.00	Spacing(m) =	1.50	Spacing(m) =	1.50
Length(m) =	30.00	Length(m) =	150.00	WetWidth(m) =	2.00
Diameter(cm) =	3.000	Diameter(cm) =	1.600	WetDepth(m) =	0.7500
Constant K =	1.6E+0005	Constant K =	1.6E+0005	Constant k =	0.4500
Friction C =	150	Friction C =	150	Exponent x =	0.5000
Exponent M =	1.8520	Exponent M =	1.8520	ManuCv(%) =	10.00
Slope(%) =	0.00	Slope(%) =	0.00	Total Plug(%) =	5.00
D-nodes(m) =	0.20	P-Degree(%) =	50.00	P-Percent(%) =	5.00

********************************** RESULTS **********************************

Coefficient of Variation of Emitter Flow CV = 30.4975%

Uniformity Coefficient of Emitter Flow UC = 80.4439%

Emitter Flow Variation qvar = 100.0000%

Submain Spatial Uniformity SPUC = 76.0495%

Wetting Pattern: ELLIPSOID

Emitter Flow Rate(LPH):	Max=	1.9414	Min=	0.0000	Average=	1.3427
Emitter Pressure(Kpa):	Max=	109.92	Min=	103.85	Average=	105.53
Irrigation Depth(m):	Max=	1.252	Min=	0.000	Average=	0.699

Simulation including: Hydraulics, Manufacture Variation, Plugging
Laterals are laid on one side of the submain.

F1-Help F2-Analysis F3-Switch Unit Esc-Exit

Figure 2.

DRIP IRRIGATION SYSTEM DESIGN AND EVALUATION COMPUTER PROGRAM

R. Yue, C. J. Phene, J.E. Ayars, I-Pai Wu, L. Kong

OBJECTIVES: To develop Comprehensive Evaluation and Design of Drip Irrigation Systems Version 5.5, which is more accurate, more useful compared with the earlier version of CEDDIS.

METHODS: CEDDIS Version 5.5 will be developed in Turbo Pascal Version 6.0, based on CEDDIS Version 1.0, 4.0 and the requirements to simulate the drip systems described in, "Field Uniformity Evaluation of Drip Irrigation Systems-Overview", of this research report. CEDDIS Version 5.5 can be run on IBM compatible personal computers.

RESULTS: CEDDIS 5.5 designs and/or evaluates drip irrigation systems by including emitter manufacturing variation and percentage of totally plugged emitters in the hydraulic calculations, as in CEDDIS Version 4.0. Percentage of partially plugged emitters is also simulated in this new version. CEDDIS 5.5 is developed to overcome the 64K memory limitation of Turbo Pascal 6.0 compiler so that user can design and/or evaluate any sizes of drip irrigation submain units as long as no negative pressure occurs inside the pipe systems. In case of zero lateral slope, the laterals may lay on either one or two sides of the submains. Both the emitter pressure and discharge profiles will be automatically saved into data files PRESSURE and DISCHARGE respectively. They can also be saved into whatever files named by the users. The maximum, minimum and average values of emitter pressures and discharge rates will be shown in the Output menu as shown in figure 2.

To keep the continuity of CEDDIS program series and to make future revision on CEDDIS easier, all the names for both parameters and files which appears in the old versions and are still required in this new version are kept unchanged. All the new parameters and files are named as the original or shorthand of the subject terms in drip irrigation area. Data input and output are processed in the same way and format as in the old versions as shown in figure 1 and 2.

CEDDIS Version 5.5 will create three temporary data files at the beginning of its operation, and from then on will continue to communicate with them. To design a drip irrigation system with Version 5.5 will need longer time than with Version 4.0. As the last step of its operation, all the three temporary data files will be automatically erased and the Output menu will come on screen to show the simulation or design results.

CEDDIS 5.5 is an user friendly program. By simply following the step-by-step instructions shown on screen, user can easily evaluate or design a drip irrigation submain unit or one lateral line by setting submain length as zero or the value of lateral spacing. The on-line Help program supply users with useful information besides defining the definitions for all the parameters.

Three basic approaches, or models, are included in CEDDIS 5.5, as in most of the earlier versions of CEDDIS. They are Energy Gradient Line(EGL) approach, Revised Energy Gradient Line(REGL) approach and Step-By-Step(SBS) approach.

INPUT MENU

CEDDIS 5.5

SUBMAIN		LATERAL		EMITTERS	
Pressure(Kpa)=	110.00	Spacing(m) =	2.00	Spacing(m) =	1.00
Length(m) =	60.00	Length(m) =	175.00	Constant k =	0.4500
Diameter(cm) =	3.800	Diameter(cm)=	1.600	Exponent x =	0.5000
Constant K =	1.6E+0005	Constant K =	1.6E+0005	ManuCv(%) =	10.00
Friction C =	150	Friction C =	150	Total Plug(%)=	5.00
Exponent M =	1.8520	Exponent M =	1.8520	P-Percent =	10.00
Slope(%) =	0.00	Slope(%) =	0.00	P-Degree(%) =	50.00
Lateral Distribution pattern along the submain:					1

Distribution: Enter number 1(2) if there is laterals along one(two) side of the submain;

Use the arrow keys to move the cursor.

Use the function keys to perform the analysis.

F1-Help F2-Analysis F3-Switch Unit Esc-Exit

Figure 1.

OUTPUT MENU

CEDDIS 5.5

**** GIVEN INFORMATION ****

SUBMAIN		LATERAL		EMITTERS	
Pressure(Kpa)=	110.00	Spacing(m) =	2.00	Spacing(m) =	1.00
Length(m) =	60.00	Length(m) =	175.00	Constant k =	0.4500
Diameter(cm) =	3.800	Diameter(cm)=	1.600	Exponent x =	0.5000
Constant K =	1.6E+0005	Constant K =	1.6E+0005	ManufactureCv=	10.00
Friction C =	150	Friction C =	150	Plugging % =	5.00
Exponent M =	1.8520	Exponent M =	1.8520	P-Percent =	10.00
Slope(%) =	0.00	Slope(%) =	0.00	P-Degree(%) =	50.00
Lateral Distribution pattern along the submain:					1

*********************** RESULT FOR THE SUBMAIN UNIT ***********************

MODEL	UC (%)	CV (%)	Qvar (%)	qmax (L/H)	qmin (L/H)	qavg (L/H)	hmax (Kpa)	hmin (Kpa)	havg (Kpa)
EGL	77.49	32.21	100.00	1.958	0.000	1.216	110.00	83.62	90.57
REGL	77.58	32.11	100.00	1.959	0.000	1.253	110.00	91.01	96.07
SBS	77.59	32.09	100.00	1.959	0.000	1.255	109.99	91.58	96.40

Simulation including: Hydraulics, Manufacture Variation, Plugging

F1-Help F2-Analysis F3-Switch Units Esc-Exit

Figure 2.

UNIFORMITY EVALUATION OF SURFACE DRIP IRRIGATION SYSTEMS AT 30AC, WATER MANAGEMENT RESEARCH LABORATORY, FRESNO, CA

R. Yue, C.J. Phene, I.P. Wu, J.E. Ayars, R. Schoneman, B. Meso

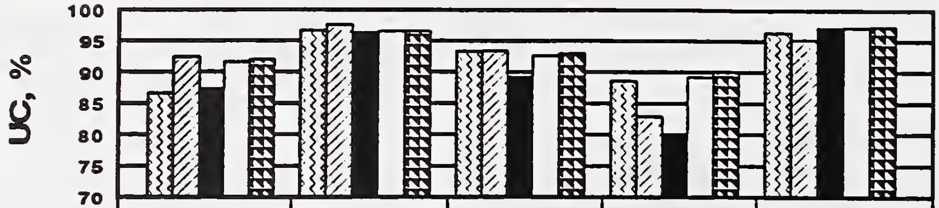
OBJECTIVES: To test and simulate the uniformity of surface drip irrigation systems laid out at 30AC of this Laboratory.

METHODS: The main reason of evaluating drip irrigation systems is to make sure that water, fertilizers and chemicals are supplied both uniformly and efficiently. This project uses three uniformity parameters: uniformity coefficient, UC, emitter flow variation, q_{var}, and coefficient of variation, CV, to express the evaluation results. In this study, five types of drip tubes: T-Tape, Typhoon, Chapin, Roberts and Ram, are evaluated by Random-18-Point and Uniform-45-Point test methods, and EGL, REGL, and SBS simulation models. The test and simulation results are then compared.

PROCEDURES: This study follows the following procedures: 1. prepare drip systems; 2. measure emitter flow rates at designed pressure; 3. calculate uniformity parameters; 4. simulate the drip systems with the three models; 5. compare test results with model simulation results. Steps for preparing the surface drip systems are: 1. lay water delivery pipes; 2. install control equipments; 3. stretch drip tubes; 4. repair leaks; 5. flushing drip systems; 6. locate testing emitters. 7. dig holes underneath test emitters for placing water receiving cups.

RESULTS: Figure 1 shows the results in terms of UC, CV and q_{var}. Figure 2 shows the differences between Uniform-40-50-Points method and model simulations. Figure 3 shows the differences between Random-18-Points method and model simulations. If a drip system has a higher UC, it will have a lower CV or q_{var}. UC is around 90%, 95%, 90%, 85% and 95% for Chapin, Typhoon, T-tape, Roberts and Ram in turn. For Typhoon, T-tape and Ram tubes, the simulation results of both REGL and SBS match the test results of either Uniform-40-50-Points method or Random-18-Points method very well, with less than 2% UC-differences; while the ones by EGL model does not match the test results as well as the ones of either SBS model or REGL model does, with a maximum UC-difference of 4.17%. There are 5.78% and 5.72% UC-differences between the two test methods for Chapin and Roberts tubes in turn. Based on the results on Roberts tube, both REGL and SBS models match Uniform-40-45-Points method better than EGL model, while worse if compared with the Random-18-Points method. That is right contrast to the results on Chapin. No water flowed out of two sections of the Chapin tubes tested. There were a lot of very small leaks along the Roberts tubes. However, it can not be concluded that plugging and leaking are the main reasons for the large differences among the two test methods and the three simulation models for the Chapin and Roberts tubes.

Results of Field Tests and Model Simulations(30AC)

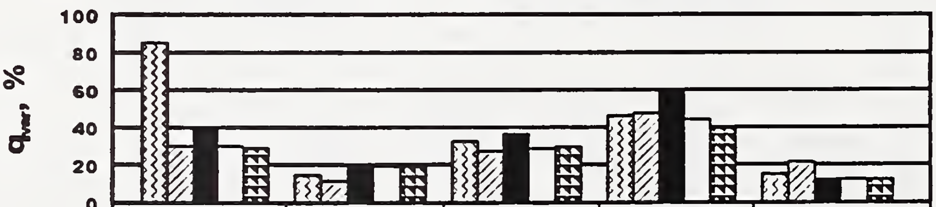


	Chapin	Typhoon	T-tape	Roberts	Ram
Test-U	86.67	96.67	93.37	88.62	96.32
Test-R	92.45	97.61	93.49	82.9	95.16
EGL	87.37	96.36	89.32	79.86	97.15
REGL	91.6	96.55	92.61	89.17	97.15
SBS	92.02	96.6	93.02	90.08	97.24
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

Results of Field Tests and Model Simulations(30AC)

	Chapin	Typhoon	T-tape	Roberts	Ram
Test-U	22.9	3.99	8.29	14.42	4.68
Test-R	9.67	3.13	8.04	20.88	6.07
EGL	15.18	4.76	12.5	24.01	3.39
REGL	10.03	4.52	8.7	13.45	3.39
SBS	9.54	4.48	8.39	12.32	3.28
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

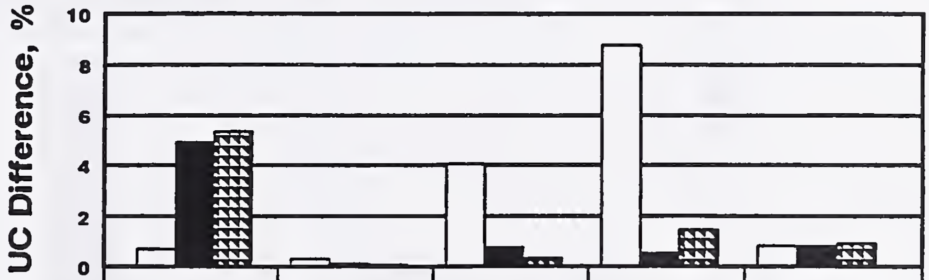
Results of Field Tests and Model Simulations(30AC)



	Chapin	Typhoon	T-tape	Roberts	Ram
Test-U	85.29	14.73	32.41	46.09	15.06
Test-R	30.1	11.41	27.09	47.55	21.45
EGL	38.82	19.59	36.44	60.13	12.28
REGL	29.99	19.08	28.68	43.95	12.28
SBS	28.92	18.99	29.71	39.21	12.28
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

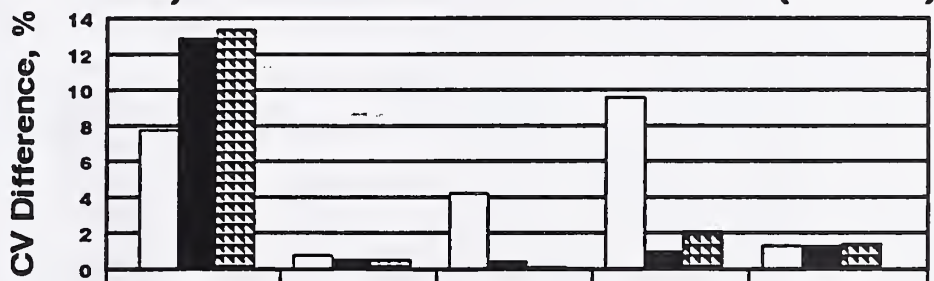
Figure 1.

Difference Between Field Tests(Uniform-40-50 Points) and Model Simulations(30AC)



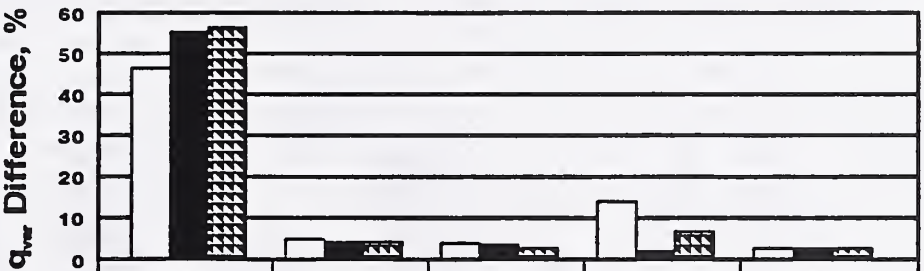
	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	0.7	0.31	4.05	8.76	0.83
REGL	4.93	0.12	0.76	0.55	0.83
SBS	5.35	0.07	0.35	1.46	0.92
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

Difference Between Field Tests(Uniform-40-50 Points) and Model Simulations(30AC)



	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	7.72	0.77	4.21	9.59	1.29
REGL	12.87	0.53	0.41	0.97	1.29
SBS	13.36	0.49	0.1	2.1	1.4
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

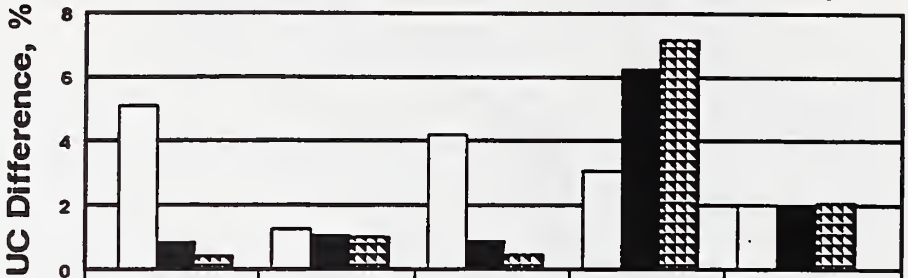
Difference Between Field Tests(Uniform-40-50 Points) and Model Simulations(30AC)



	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	46.47	4.86	4.03	14.04	2.78
REGL	55.3	4.35	3.73	2.14	2.78
SBS	56.37	4.26	2.7	6.88	2.78
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

Figure 2.

Difference Between Field Tests(Random-18 Points) and Model Simulations(30AC)

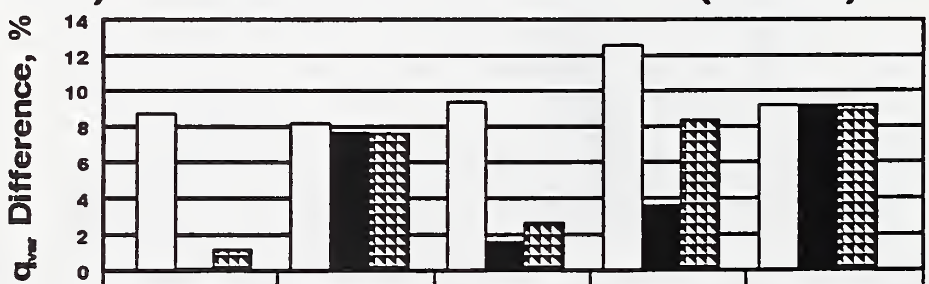


	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	5.08	1.25	4.17	3.04	1.99
REGL	0.85	1.06	0.88	6.27	1.99
SBS	0.43	1.01	0.47	7.18	2.08
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

Difference Between Field Tests(Random-18 Points) and Model Simulations(30AC)

	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	5.51	1.63	4.46	3.13	2.68
REGL	0.36	1.39	0.66	7.43	2.68
SBS	0.13	1.35	0.35	8.56	2.79
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

Difference Between Field Tests(Random-18 Points) and Model Simulations(30AC)



	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	8.72	8.18	9.35	12.58	9.17
REGL	0.11	7.67	1.59	3.6	9.17
SBS	1.18	7.58	2.62	8.34	9.17
x-value	0.5156	0.5096	1	0.7074	0
Length, m	201	203	201	407	409

Figure 3.

WATER QUALITY MANAGEMENT WESTSIDE OF SAN JOAQUIN VALLEY- BRITZ PROJECT I. GROUNDWATER QUALITY MAPPING

J.E. Ayars, J. Penland, R.A. Schoneman, and B. Meso

<u>OBJECTIVES</u>: Monitor the electrical conductivity, boron, and nitrate in the shallow groundwater below the test site over time and prepare iso-concentration maps of constituents in the shallow groundwater.

<u>PROCEDURES</u>: Shallow groundwater observation wells constructed of 50 mm PVC pipe were installed to a depth of 2.4 m throughout the research site as shown in Figure 1. The wells were installed adjacent to the neutron access tubes. Water samples were collected approximately every two weeks and analyzed for electrical conductivity, boron, nitrate, selenium and most of the major anions and cations. The data were plotted using the topographical plotting system found in the program "Surfer."

<u>RESULTS</u>: Examples of the prepared maps are given in figures 2 and 3. Figure 2 shows the distribution of electrical conductivity in the shallow groundwater in August of 1992. The values range from 4 to 12 dS/m. Also, the locations of the drip and furrow irrigation systems are shown. The data have to be carefully interpreted when using this system because the program fits the data entered and when an extreme value is entered it is included in the analysis also. In Figure 2 it is possible that the 14 dS/m value is an outlier and should not be included in the plot. The boron concentrations taken on August 14, 1992 don't show a spiked value at the same location as the high EC.

<u>FUTURE PLANS</u>: We will continue to use the same sampling pattern as shown in Figure 1 in future years and will continue to plot the contours using this program with the knowledge that outlier values can drastically modify the interpretation of the data. This plotting strategy will be used in subsequent reports.

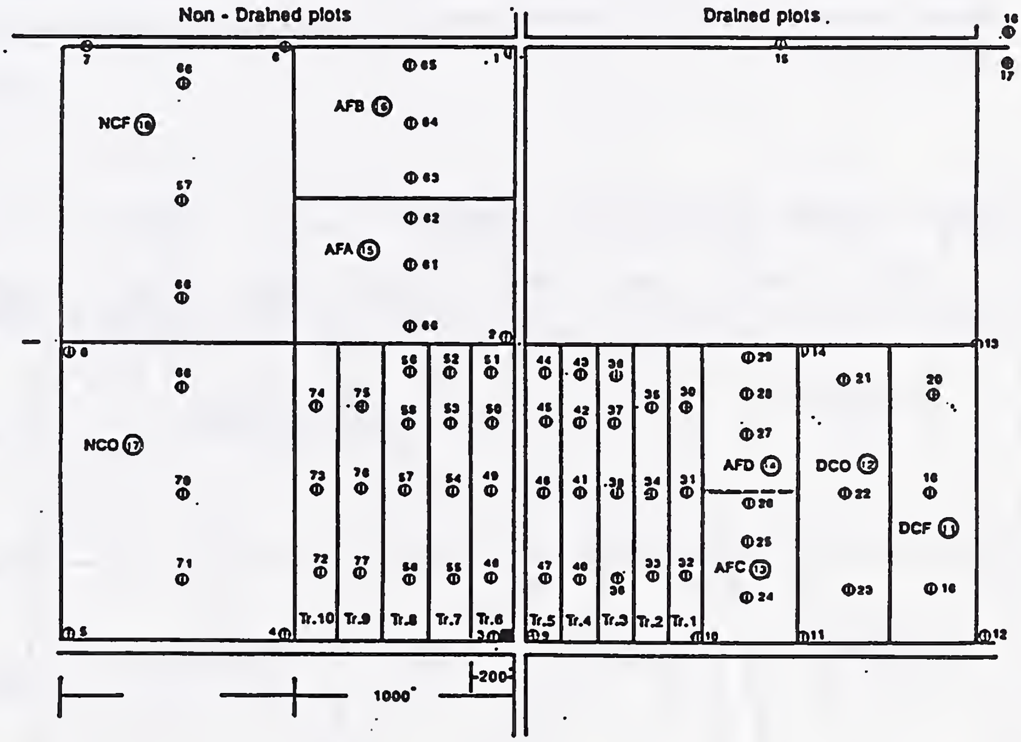


Figure 1. Map of observation wells installed on the Britz Research Site in 1993.

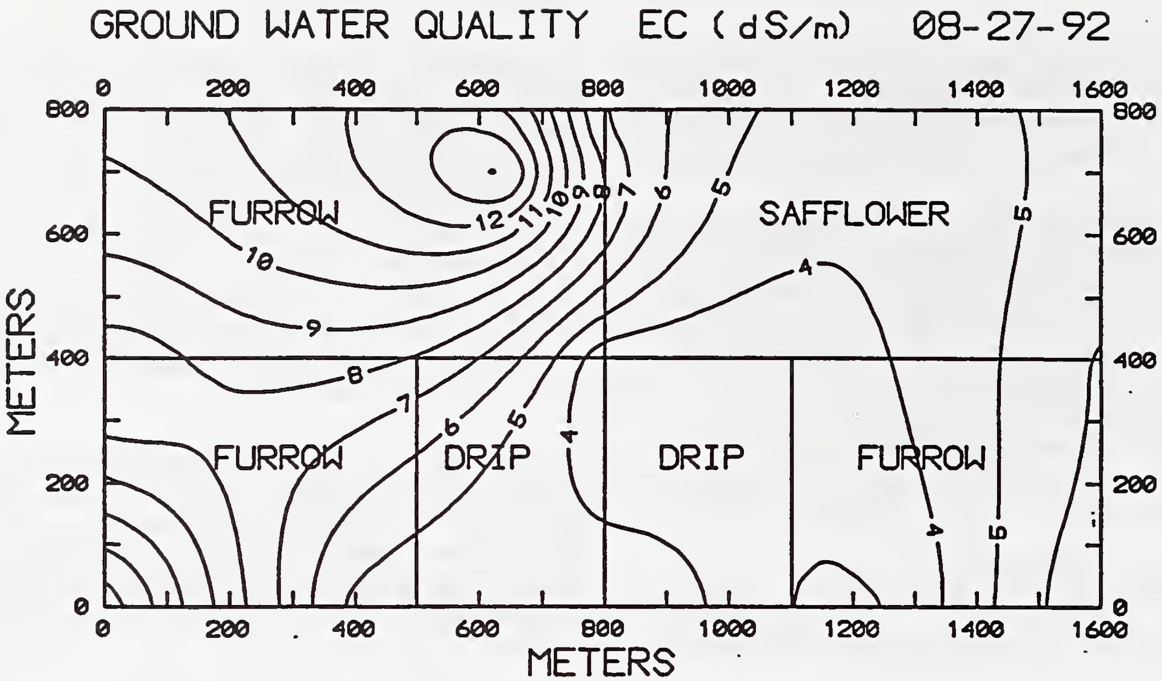


Figure 2. Map of electrical conductivity of shallow groundwater under Britz demonstration site on August 27, 1992.

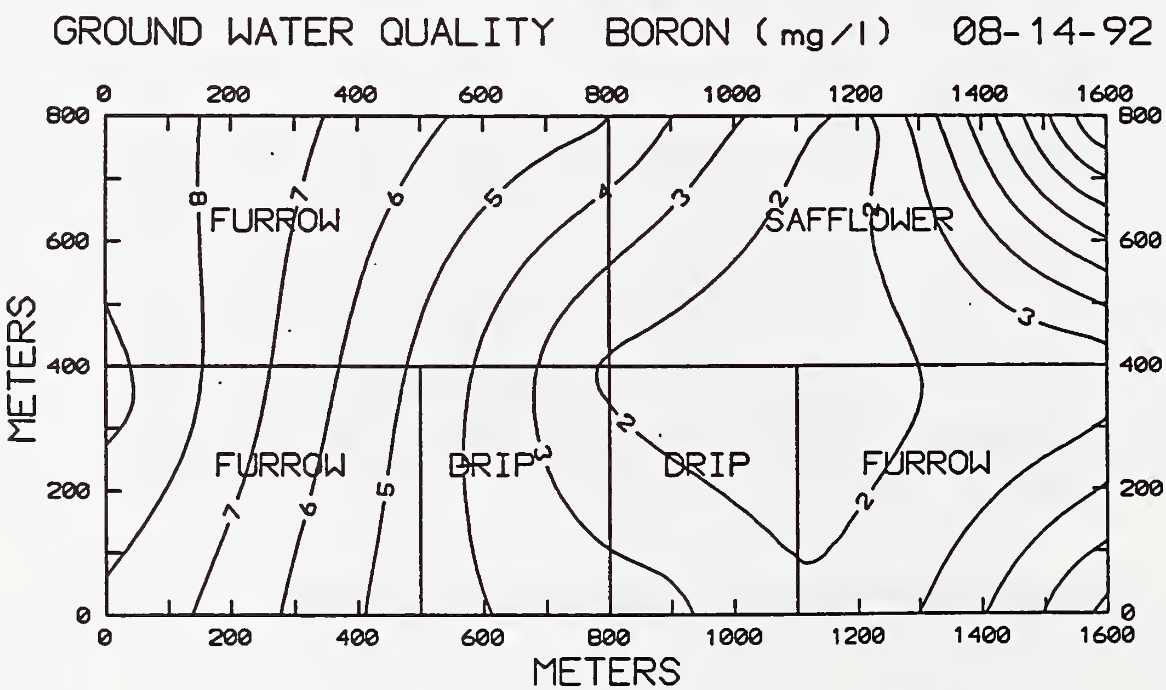


Figure 3. Map of boron concentration in shallow groundwater under Britz demonstration site on August 14, 1992.

WATER QUALITY MANAGEMENT WESTSIDE OF SAN JOAQUIN VALLEY–BRITZ PROJECT II. SUMMARY OF REPAIRS

M.K. Beta, R.A. Schoneman, F. Dale, J.W. Penland and J.E. Ayars

OBJECTIVES: Review and adjust our plans in order to avoid the damages observed in 1991.

METHOD: The entire field area and the irrigation system station were inspected to identify all tubing problems such as: disconnection of the drip tube couplings, tubing cuts by gopher colonies.

RESULTS: A total of twenty four (24) repairs of disconnected drip tube couplings were made in comparison to the forty–eight disconnections repaired in the first season.

The major problems with the tubing were chewing and cutting of the drip tubings by gophers and tractors. The presence of many gopher colonies around the field is causing considerable damage by their chewing of the drip tubes. Many spots of gopher pockets were found in the treatment 1, 2, 3, 4, 6, 7, DCO, AFC; in which fifty–four (54) damaged areas were repaired. Cutting of drip tubings: The most damage was done by the tractor field work: discing, cultivating, etc. The change of rowbed spacing from 66 inches in the first year in the north field to 40 inch beds in the second year caused disturbance in the drip tube alignment and depth, leaving many close to the surface. As a result the tubing was easily pulled out and cut. A total of seventy one (71) repairs were done in this season (see table).

CONCLUSION: Most of the damage done by cutting occurred at the head and tail end of the tubing run where the tubing was not installed at a depth of 18".

Gophers and other rodents are significant pests and their control is essential especially when tape type tubing is being used.

Tubing repair

Treatments	:	1	2	3	4	5	6	7	8	9	10
Cut	:	7	4	8	10	2	6	13	15	4	371
Chewing	:	17	2	4	13	8	–	3	4	1	254
Dislocation	:	4	2	6	1	6	–	3	2	–	–24
		28	8	18	24	16	6	19	21	5	5149

WATER QUALITY MANAGEMENT WESTSIDE OF SAN JOAQUIN VALLEY-BRITZ PROJECT III. WATER TABLE RESPONSE

J.E. Ayars, R.A. Schoneman, B. Meso, J. Penland

OBJECTIVES: Quantify the change in depth to the shallow groundwater under each of the irrigation systems being used in the project.

PROCEDURES: The depth to shallow groundwater was measured throughout the field using the shallow water table wells identified in Figure 1 of the report on groundwater quality mapping. The measurements were made at the time the groundwater was sampled for water quality. The elevation of the top of each shallow well were surveyed and referenced to an arbitrary datum. Change was calculated from the measured depth. The total change was plotted using the program Surfer.

RESULTS: The change in water table depth for the period March 18, 1992 to August 27, 1992 is plotted in Figure 1. The data show that the depth to water increased from 0.5 to 1.4 m during the growing season. The water table was at a depth of approximately 1 m below the soil surface at the beginning of the season and increased to in excess of 2 m by the end of the season. The largest increases occurred under the safflower which was being grown expressly to reduce the water table depth. The average change in water depth was approximately the same for both the drip and furrow plots. The change in water table level indicates that a significant quantity of water was extracted from the shallow groundwater by the cotton.

FUTURE PLANS: Shallow water table monitoring wells will be installed at approximately the same locations in subsequent years to monitor changes in water table under other crops.

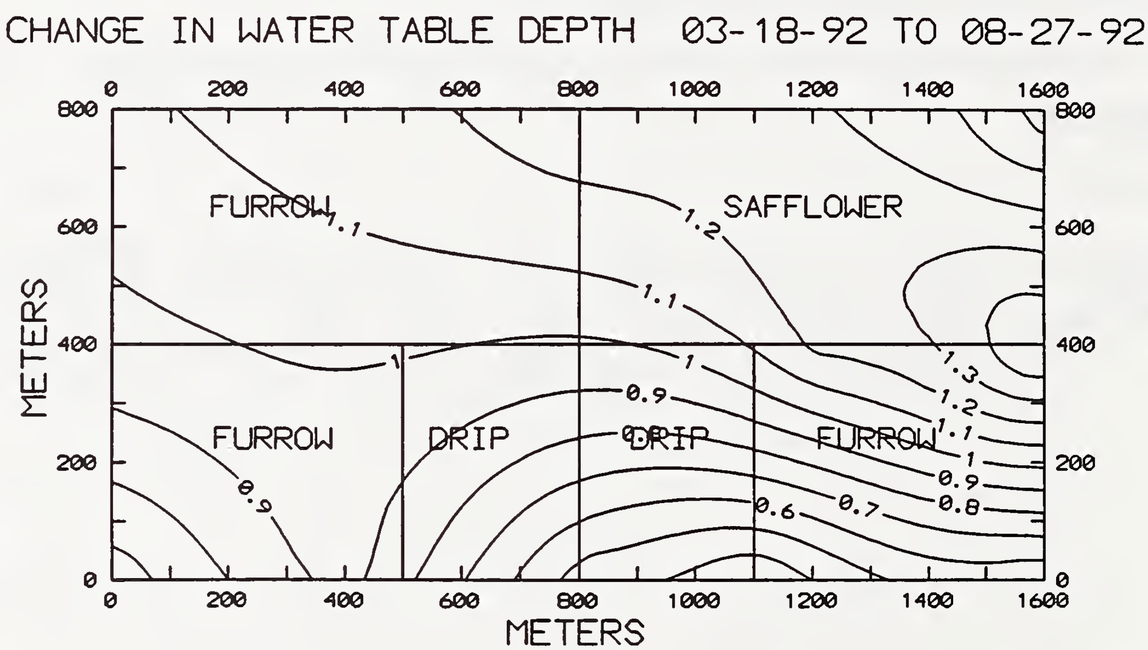


Figure 1. Change in water table depth below Britz Demonstration project between March 18, 1992, and August 27, 1992.

WATER QUALITY MANAGEMENT WESTSIDE OF SAN JOAQUIN VALLEY–BRITZ PROJECT IV. MANAGING SUBSURFACE DRIP TO INDUCE SHALLOW GROUNDWATER USE BY COTTON

J.E. Ayars, R.B. Hutmacher, R.A. Schoneman, D.A. Clark

OBJECTIVES: Develop a methodology to use research data on crop water use from shallow saline groundwater collected in column lysimeters to control the operation of a subsurface drip system operated in the presence of shallow saline groundwater.

PROCEDURES: Crop water use from saline groundwater in the column lysimeters (up to 7 dS/m) was calculated as a percentage of crop water use. This percentage use was tabulated along with the accumulated growing degree days for the cotton in the lysimeters. Then growing degree days were accumulated in the field crop and the irrigation system was set to apply the estimated average daily use for the week less the percentage taken from the groundwater. For instance if the weekly average crop water use was 5 mm per day and the lysimeter data indicated that nearly 50% of the water use could be met by shallow groundwater, then the drip system was set to apply a total of 2.5 mm per day. The percentage use from groundwater changes throughout the season as does the crop water use. The adjustments to daily application were made weekly. Leaf water potential data were used to monitored the stress levels in the crop and determine if the irrigation schedule should be modified.

RESULTS: Leaf water potential (LWP) data for plot 9 are given in Figure 1. The data show that there was a mild stress 16 to 17 bar early in the season. This occurred at a time when the ET_c was averaging approximately 3 to 4 mm per day and the drip system was applying approximately 2mm per day. The depth of application was increased to nearly 5 mm per day for 1 week and then to 8 mm per day for the following week at which time the application was reduced to 5 mm per day for the remainder of the season. The average ET_c and daily application for the time period June 10 to August 29 are shown in Figure 2. After the 2 week period of increased application the leaf water potential decreased to approximately 14 bars and remained there for the remainder of the season. A leaf water potential of 14 bars indicates that the crop is well watered. Since the irrigation application was under the ET_c for this time period and the LWP indicated well watered plants it is likely that the cotton was using significant quantities of shallow groundwater. These results indicate that data on shallow groundwater use obtained from column lysimeters can be used to guide the operation of irrigation systems being operated in the presence of shallow groundwater.

FUTURE PLANS: Data for percent shallow groundwater use from column lysimeters will be used along with growing degree data and plant development data to modify the cotton crop coefficient to account for use from shallow groundwater.

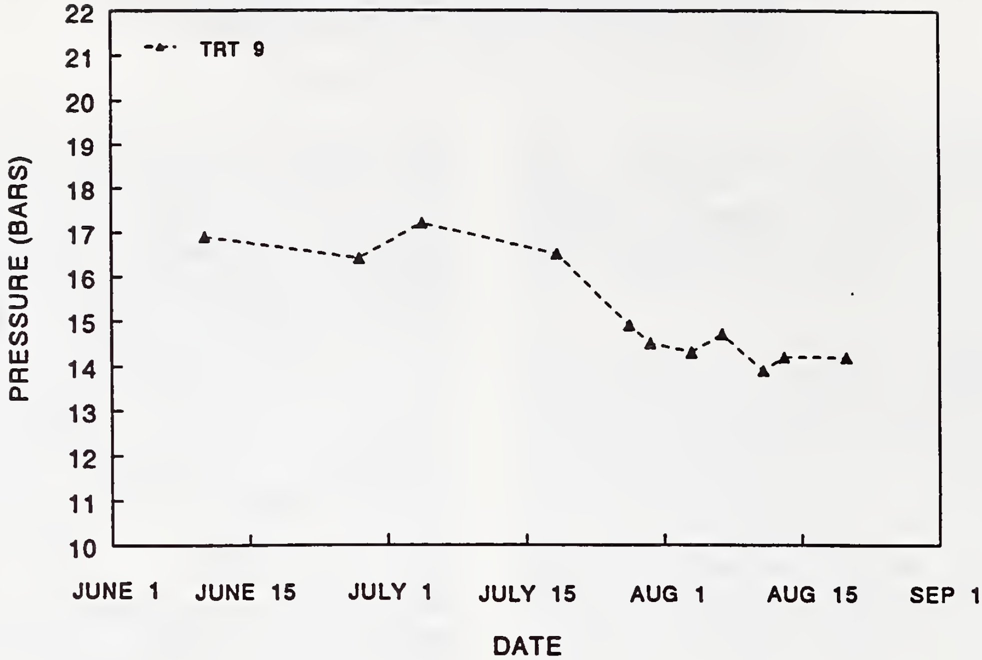


Figure 1. **Leaf water potential in cotton grown in Treatment 9 of the Britz Demonstration project in 1992.**

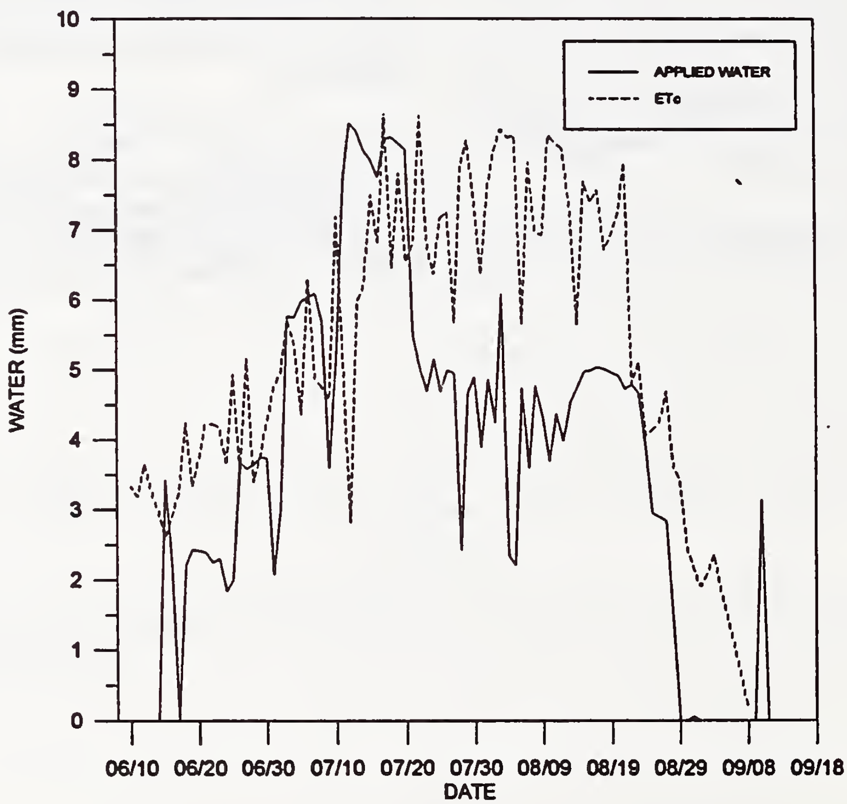


Figure 2. **Daily average evapotranspiration and applied water in Treatment 9 of the Britz Demonstration Project in 1992.**

WATER QUALITY MANAGEMENT WESTSIDE OF SAN JOAQUIN VALLEY–BRITZ PROJECT V. COTTON YIELD

J.E. AYARS, B. MESO, R.A. SCHONEMAN

OBJECTIVES: Determine the yield of cotton in each of the drip and furrow irrigated plots.

PROCEDURES: Cotton (Acala, Maxxa) was planted on April 13–14, 1992 at a seeding rate of 20 kg/ha with germination being observed on April 20–21, 1992. Defoliation was done September 9, 1992 and harvest occurred October 20–23, 1992. Yields were determined using machine harvest data.

RESULTS: The plant population ranged from 78,000 to 129,000 plants per ha. The average lint yield was 1500 kg/ha and 1100 kg per ha in the drip and furrow plots, respectively. The yield in the individual plots is given in Table 1.

There was a distinct difference in the yields between the north and south fields. The yields in the north field (plot 6, 7, 8, 9, 10, NCO/NCF) were consistently higher than in the plots in the south field. This was a result of a combination of stand problems and possibly salinity problems. The potential salinity problems are still being investigated. The difference in plant population is noted in Table 1.

FUTURE PLANS: The project will continue in 1993 with tomatoes being grown in the north field and cotton being grown in the south field.

Table 1. Plant population and yield data for research plots at Britz Demonstration Project.

Plot	Lint (kg/ha)	Plant Population #/ha (1000)
1	827	88
2	863	103
3	893	85
4	992	107
5	972	108
6	1910	98
7	2100	104
8	2160	107
9	2140	120
10	2140	135
NCO/NCF	2177	119/113
AFC/AFD	722	78
DCO	674	
DCF	724	129.7

WATER QUALITY MANAGEMENT WESTSIDE OF SAN JOAQUIN VALLEY-BRITZ PROJECT VI. WATER BALANCE

J.E. Ayars, R.A. Schoneman, B. Meso and J. Penland

OBJECTIVES: Determine the water application and evapotranspiration by plot for each of the drip and furrow irrigated plots and estimate potential groundwater contribution.

PROCEDURES: The water application to the drip plots was measured using water meters on each plot and the application to the furrow plots was also measured with water meters. The furrow plots blocked furrows and as a result there was no surface runoff. Evapotranspiration was estimated using CIMIS data and a crop coefficient and with a class A evaporation pan located on site. The evaporation pan data were modified using a crop coefficient and a pan coefficient. Also, actual crop water use was estimated using the dry matter production function TDM = -2.94+0.03 ET where TDM is total dry matter in T/ha and ET is in mm (Davis 1983). There were a total of 4 irrigations applied by furrow during the growing season. The last three irrigations in the north field were done using a surge valve. Daily drip irrigation began on June 6, 1992.

RESULTS: Pre-plant irrigation was applied from October 8, 1991 to October 20, 1991. Approximately 310 and 307 mm were applied to the north and south fields, respectively. The seasonal applied water and the ET_c estimated using the dry matter production function are given in Table 1. The ET_c for the period from germination to harvest using the CIMIS data was 857 mm and 813 mm based on the evaporation pan data. The data in Table 1 show there was a potential for cotton to use water from the water table. The data for change in depth to the water table indicate that there was a significant contribution to crop water use from the water table.

FUTURE PLANS: Water balance data will continue to be collected from these sites in subsequent years.

Table 1. Seasonal applied irrigation water and estimated ET_c based on dry matter production function.

PLOT	APPLIED WATER (mm)	ESTIMATED ETc (mm)
1	300	455
2	377	577
3	380	555
4	378	613
5	390	594
6	353	607
7	340	607
8	354	640
9	354	646
10	368	697
AFA/AFB	576	567
AFC/AFD	475	333
DCF	475	437
NCF	576	520
NCO (S)*	462	625
DCO	475	416

* Indicates surge irrigation was used.

WATER QUALITY MANAGEMENT WESTSIDE OF SAN JOAQUIN VALLEY-BRITZ PROJECT VII. NITRATE CONCENTRATION IN SHALLOW GROUNDWATER UNDER COTTON CROP.

J.E. Ayars, R.A. Schoneman and M.K. Beta,

OBJECTIVES: Determine the influence of irrigation management on nitrate concentration in shallow groundwater under a cotton crop.

PROCEDURES: A grid of shallow groundwater observation wells was installed throughout the test area (see report 1). Water samples were taken approximately every two weeks and analyzed for nitrates as well as the major anions and cations. An average of 100 kg/ha of nitrogen was applied to the subsurface drip plots and 170 kg/ha of nitrogen was applied in the furrow irrigated plots. Approximately 25 kg/ha of phosphorous was applied to the drip plots. As noted in a previous report on average the drip plots had higher yields than did the furrow plots. The nitrate concentration data were plotted using the program Surfer.

RESULTS: The change in NO_3^-– N concentration for the time period March 18,1992 to August 27, 1992 is given in Figure 1. The change ranged from 100 mg/l to 0 mg/l. Part of the change is an artifact due a very high concentration of nitrate found in a well on the border of the field. A reduction in concentration the range of 20 to 30 mg/l is probably a good approximation of what occurred. The nitrate concentration in the groundwater on August 14, 1992 is shown in Figure 2. These values still exceed the concentrations recommended for drinking water standards. This should not be a problem since this water is not used as a potable water supply.

FUTURE PLANS: We will continue to monitor water quality in subsequent years of the project.

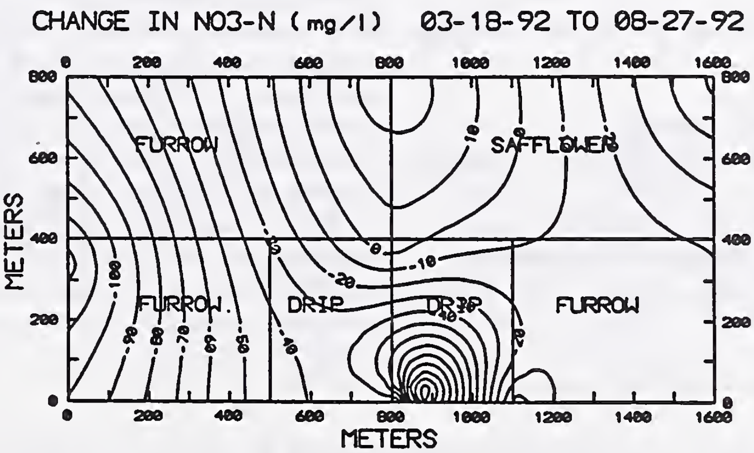


Figure 1. Change in nitrate concentration in shallow groundwater under the Britz demonstration project between March 18, 1992, and August 27, 1992.

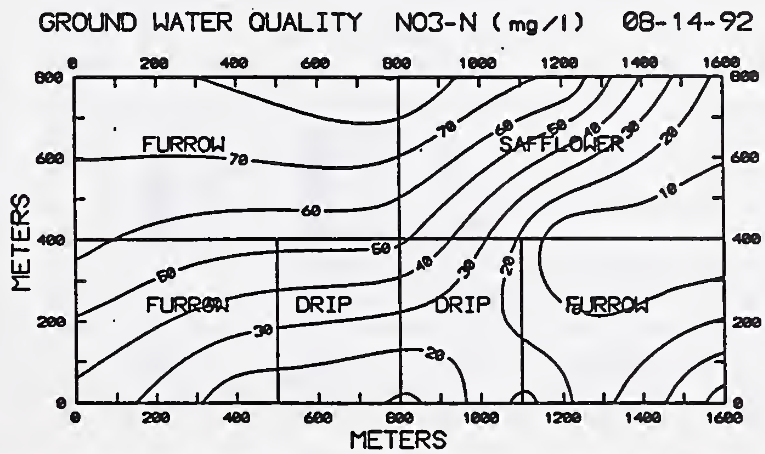


Figure 2. Nirate concentration in the shallow groundwater under the Britz demonstration project on August 24, 1992.

UNIFORMITY EVALUATION OF SUBSURFACE DRIP IRRIGATION SYSTEMS AT BRITZ FARM, MENDOTA, CA

R. Yue, C.J. Phene, I-Pai Wu, F. Dale
J.E. Ayars, R. Schoneman, B. Meso, L. Kong

OBJECTIVES: To test and simulate the uniformity of subsurface drip irrigation systems at Britz Farm.

METHODS: This evaluation covers five types of subsurface drip systems installed at Britz Farm: T-Tape, Typhoon, Chapin, Roberts and Ram. Their operating pressure at the inlet of mainlines are 17, 16, 16, 10 and 33 psi in turn. Each treatment is 200 ft wide and 1300 ft long. The drip tubes are buried about 18 in deep. Each treatment contains 30 drip tubes. Please refer to earlier Research Progress Report for more details on those systems. The field test is carried out by Random-18-Point method. The systems are evaluated by simulation models EGL, REGL and SBS.

PROCEDURES: This study follows the following procedures:

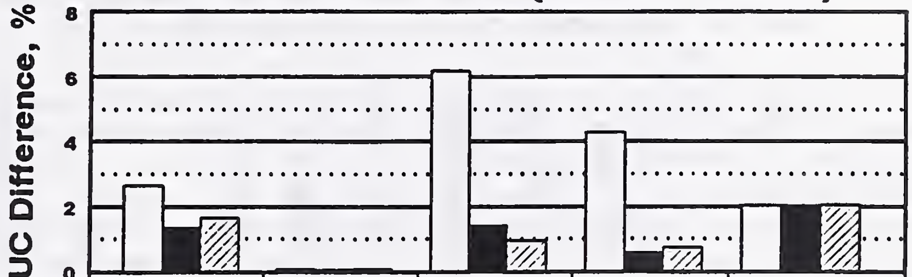
1. Prepare the drip systems;
2. Measure emitter flow rates at designed pressure;
3. Calculate uniformity parameters;
4. Simulate the drip systems with models;
5. Compare the test results with model simulation results.

Steps for preparing the subsurface drip irrigation systems are:

1. Expose flushing holes;
2. Install flushing risers;
3. Repair leaks due to machine damages, gopher damages and loose connectors;
4. Flushing drip systems;
5. Locate testing points;
6. Expose testing emitters.

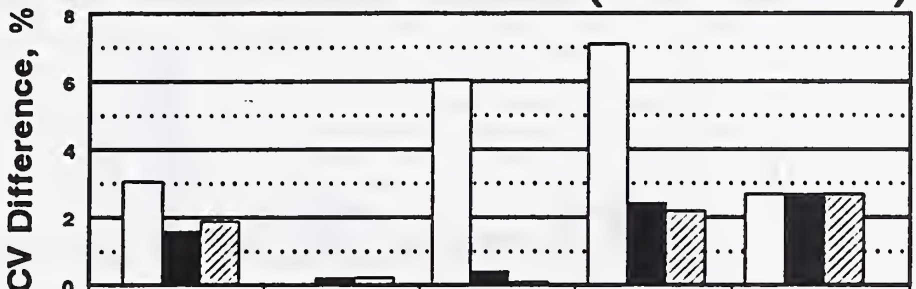
RESULTS: Figure 1 shows the results in terms of UC, CV and q_{var}. Figure 2 shows the differences between field tests and model simulations. If a drip system has a higher UC, it will have a lower CV or q_{var}. UC is around 90%, 95%, 90%, 75% and 95% for Chapin, Typhoon, T-tape, Roberts and Ram in turn. The model simulation results match the field test results, with less than 3% UC or CV differences between either REGL or SBS model and field tests, and less than 8% UC or CV differences between EGL model and field tests. REGL model has almost the same results as SBS model. The values of q_{var} and the q_{var} differences among the field tests and model simulations indicated that q_{var} is no longer a good parameter to express drip irrigation uniformity if either or both emitter plugging and manufacturing variation need to be considered. Two of the 20 emitters dug out were totally plugged in Roberts treatment. No emitter was found plugged in all the other treatments.

Difference Between Field Tests and Model Simulations(Britz Farm)



	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	2.65	0.09	6.19	4.29	2.04
REGL	1.36	0.07	1.42	0.58	2.04
SBS	1.66	0.09	0.95	0.74	2.05
x-value	0.5156	0.5091	1	0.7074	0
Length, m	198.25	198.25	198.25	396.5	396.5

Difference Between Field Tests and Model Simulations(Britz Farm)



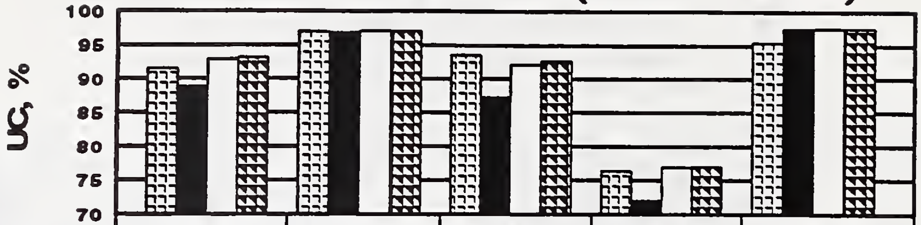
	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	3.05	0.01	6.04	7.1	2.67
REGL	1.58	0.19	0.41	2.41	2.67
SBS	1.88	0.21	0.11	2.19	2.68
x-value	0.5156	0.5096	1	0.7074	0
Length, m	198.25	198.25	198.25	396.5	396.5

Difference Between Field Tests and Model Simulations(Britz Farm)

	Chapin	Typhoon	T-tape	Roberts	Ram
EGL	14.72	6.87	11.75	0	2.18
REGL	6.75	6.38	1.39	0	2.18
SBS	6.41	6.34	0.37	0	2.18
x-value	0.5156	0.5096	1	0.7074	0
Length, m	198.25	198.25	198.25	396.5	396.5

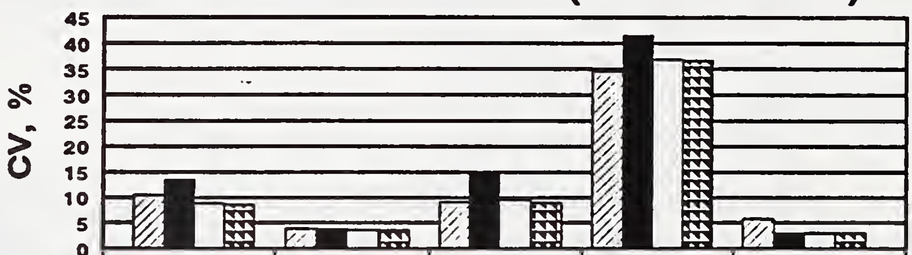
Figure 2.

Results of Field Tests and Model Simulations(Britz Farm)



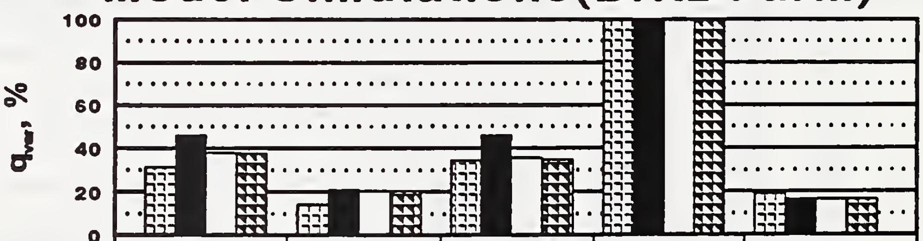
	Chapin	Typhoon	T-tape	Roberts	Ram
Field Test	91.5	96.97	93.57	76.34	95.47
EGL	88.85	96.88	87.38	72.05	97.51
REGL	92.86	97.04	92.15	76.92	97.51
SBS	93.16	97.06	92.62	77.08	97.52
x-value	0.5156	0.5096	1	0.7074	0
Length	198.25	198.25	198.25	396.5	396.5

Results of Field Tests and Model Simulations(Britz Farm)



	Chapin	Typhoon	T-tape	Roberts	Ram
Field Test	10.42	3.94	9.11	34.49	5.78
EGL	13.47	3.95	15.15	41.59	3.11
REGL	8.84	3.75	9.52	36.9	3.11
SBS	8.54	3.73	9	36.68	3.1
x-value	0.5156	0.5096	1	0.7074	0
Length, m	198.25	198.25	198.25	396.5	396.5

Results of Field Tests and Model Simulations(Britz Farm)



	Chapin	Typhoon	T-tape	Roberts	Ram
Field Test	31.15	14.04	34.2	100	18.69
EGL	45.87	20.91	45.95	100	16.51
REGL	37.9	20.42	35.59	100	16.51
SBS	37.56	20.38	34.57	100	16.51
x-value	0.5156	0.5096	1	0.7074	0
Length, m	198.25	198.25	198.25	396.5	396.5

Figure 1.

WATER QUALITY MANAGEMENT WESTSIDE OF SAN JOAQUIN VALLEY-BRITZ PROJECT VIII. LYSIMETER CONSTRUCTION

J.E. Ayars, A. Schneider, C.J. Phene, R.A. Schoneman and M.K. Beta

OBJECTIVES: Design and collect soil monolith for weighing lysimeters using soil collected in areas with shallow groundwater.

PROCEDURES: The lysimeter dimensions are m by 4m by 2.7m deep. The tank was built in two sections with the top section being 1.67 m deep and the bottom section being 1.1 m deep (Figure 1). The top section was used to collect an undisturbed monolith while the bottom section was backfilled by hand.

RESULTS: Two monoliths were successfully extracted from the soil using the equipment shown in Figure 2. The empty tanks were set on the soil and pushed into the soil using dead weight made up of the bottom tanks and the undercutting plates. The rate of movement and the level of the tanks was controlled by 5 ton hoists which were attached at each corner of the tank and to a lowering frame located at each end of the tank. After the tank was fully inserted, steel plates were pulled under the tank and used to secure the monolith when it was lifted from the site. Two monoliths were removed and transported from the site in approximately 4 working days. Soil was excavated from below the monolith for use in backfilling the respective bottom tanks. The procedure made it possible to maintain the soil salinity profile which had been established above saline shallow groundwater.

FUTURE PLANS: The lysimeters will be instrumented and installed in a three acre site at the USDA-ARS location in Parlier, Ca.

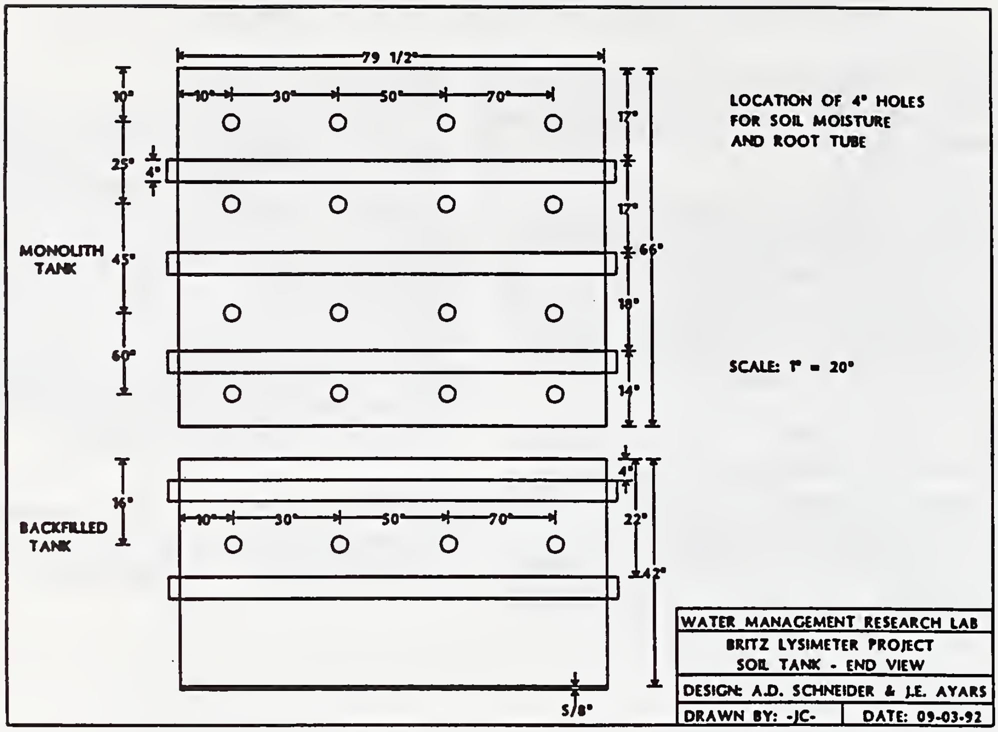


Figure 1. End view of lysimeter tank being used for water and salt transport studies on the Britz demonstration project.

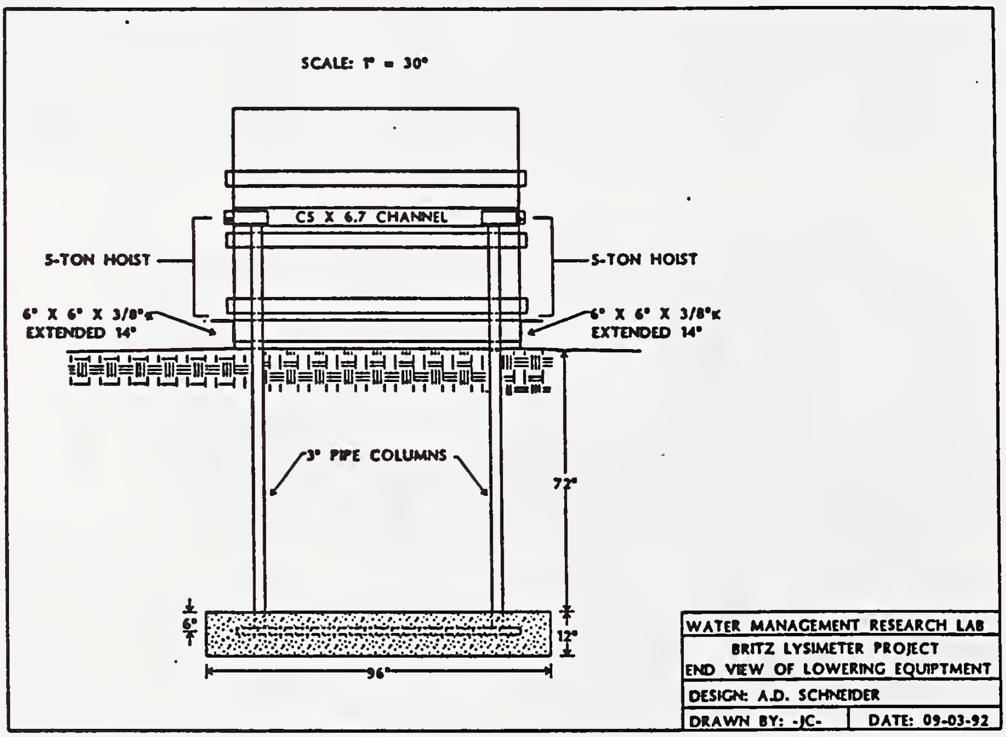


Figure 2. End view of lowering equipment and monolith tank used to collect undistrubed soil monolith for lysimeter studies on the Britz demonstration project.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATION IN THE IMPERIAL VALLEY OF CALIFORNIA: FORAGE ALFALFA: SYSTEM OPERATION AND MANAGEMENT

C.J. Phene, R.B. Hutmacher, R.M. Mead, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes, J. Rhoades, K.R. Davis, R.A. Schoneman, D. Dettinger, A. Bravo, M. Jones

OBJECTIVES: The alfalfa subsurface drip irrigation/furrow irrigation experiment at the Irrigated Desert Research Station in Brawley, CA, is a five-year evaluation of alfalfa water requirements and the long-term influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. This experiment focuses on the comparison of crop responses, irrigation water requirements, and salinity accumulations as affected by subsurface drip versus furrow irrigation. In addition, the influence of two drip lateral spacings will also be evaluated.

PROCEDURES: Treatments were as described in "Water management requirements of subsurface drip irrigation in the Imperial Valley: Operational Procedures" (elsewhere in this report). Three replications of each of five irrigation treatments were investigated in this experiment. There are two drip lateral spacing treatments, 40 inch (1.02 m) and 80 inch (2.04 m), with the drip laterals placed 40 cm below the center of each bed, on 40 inch and 80 inch beds, respectively. Two different types of drip tubing were used with each row spacing: (a) pressure-compensating in-line emitters on 20 mm tubing; and (b) turbulent-flow in-line emitters made out of herbicide-impregnated plastic. Both emitter types have a nominal flow of 2 L h^{-1} at 18 to 20 psi. Emitter spacing along the laterals is 40 inches (1.02 m) in both types of tubing.

Phosphoric acid was continuously injected in the irrigation water in all drip plots to achieve a final concentration of 15 mg P L^{-1}. An initial broadcast application of a phosphorus-containing fertilizer supplied 55 kg P ha^{-1} in all plots, and side-dress applications of phosphorus were made in furrow-irrigated plots to equal season total P applications in drip plots.

RESULTS: *System Operation and Management.* Over the 19 months of operation of the original system, the most persistent problems with the drip plots have been with development of "wet" and "dry" areas within the field. The areas affected have been relatively limited in size (less than 3 to 5% of the bed surface areas with each problem), however, they demand attention due to their influence on irrigation management and harvesting operations. Our preliminary conclusions are that the areas with "wet" surface areas (free water on the soil surface) are a result of both too shallow placement of the drip laterals (at 35 to 40 cm) for a soil of this texture and a limited number of malfunctioning emitters.

Root intrusion problems have not been observed to date in emitters within the dry areas, and are not thought to be a significant cause of emitter plugging. Work is continuing to look at the irrigation water chemistry, silt load and fertilizer solution compatability to determine if any emitter plugging problems can be traced to those problem areas. Malfunctioning or missing emitters and some plugging associated with silt entering the system during the early phases of installation have been the usual cause of "dry" areas noted in the field.

Even with the drip laterals placed 40 cm below the soil surface, water was repeatedly observed at the surface of the soil in all drip irrigation treatments. Even considering that the total affected field surface area was small, wet surface soils during harvest periods caused significant trafficability problems. The most consistent problem areas were with heavy harvest equipment driving over beds with sporadic wet soil surfaces. After the initial soil compaction and damage to plant crowns, problems recurred during much of the season, particularly during high ET periods when daily water application amounts were high. To limit this problem, drip irrigation was scaled down to 25-50% of lysimeter application amounts during the 4 to 6 days prior to harvest through bale removal. This could produce some short-term water stress similar to the same period under furrow irrigation. It remains important to determine suitable tubing installation depths and irrigation management strategies that will have less impact on harvest operations and forage yields.

FUTURE PLANS: After completion and testing of the newly installed drip lines in late spring of 1993 (installed at a depth of 25 to 27 inches (63 to 73 cm), a sudan grass crop will be planted as a cover crop for the spring and summer months. The alfalfa experiment will resume in the fall of 1993, with planting scheduled for October.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATION IN THE IMPERIAL VALLEY OF CALIFORNIA: FORAGE ALFALFA: CROP WATER USE, SOIL WATER DEPLETION

C.J. Phene, R.B. Hutmacher, R.M. Mead, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes, J. Rhoades, K.R. Davis, R.A. Schoneman, D. Dettinger, A. Bravo, M. Jones

OBJECTIVES: The alfalfa subsurface drip irrigation/furrow irrigation experiment at the Irrigated Desert Research Station in Brawley, CA, is a five-year evaluation of alfalfa water requirements and the long-term influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. This experiment focuses on the comparison of crop responses, irrigation water requirements, and salinity accumulations as affected by subsurface drip versus furrow irrigation. In addition, the influence of two drip lateral spacings will also be evaluated.

PROCEDURES: Treatments were as described in "Water management requirements of subsurface drip irrigation in the Imperial Valley: Operational Procedures" (elsewhere in this report). Treatments T1 through T4 were subsurface drip irrigation treatments and treatment T5 was furrow-irrigated.

RESULTS: *Crop Water Use:* Total applied water during January through November of 1992 is shown in Figure 1. Total applied water in 1992 (through termination of the alfalfa crop in November) was similar across irrigation treatments and averaged 1365 mm (53.7 inches) in drip treatments and 1491 mm (58.7 inches) in the furrow-irrigated treatment (T5). This compared with an average of 1174 mm for drip treatments for a partial season in 1991 versus 1310 mm in the 1991 furrow treatment. Total water application in drip plots averaged 7% less than furrow plots during the period from initial planting in 1991 through termination of the first alfalfa crop in November, 1992.

Beginning in June of 1992, we began working with Mr. Dean Currie of Elmore Farms to assist in matching irrigation scheduling in furrow plots to those typical for alfalfa production in commercial fields in similar soils in the Imperial Valley. The lysimeter represents water use of a completely non-water-stressed control, since the lysimeter was hand-harvested and irrigations were uninterrupted and matched evapotranspiration as measured using the lysimeter. Soil water contents throughout the lysimeter soil profile remained quite high and uniform over time.

In the furrow plots, typical practices for the Imperial Valley were followed,which included application of the last irrigation of each harvest cycle 5 to 7 days prior to each harvest. The first irrigation of each cycle occurred immediately after bale removal. Due to problems with wet surface soils even in the drip plots (described in a separate report), irrigations in the drip plots during this "dry-down" period of each harvest cycle were reduced to 25% to 50% of lysimeter water applications. This resulted in lower ET and Crop Water Stress Index (CWSI) measurements in drip and furrow-irrigated plots indicated CWSI values of 0.15 to 0.2 were common during these periods preceding harvest.

Estimates of stored soil water use in the 60 to 180 cm depths ranged from about 11.4 cm to 18 cm during the 1992 measurement period. Rainfall of less than 12 cm during both 1991 and 1992 resulted in little replenishment of depleted soil water from rainfall. Water applied with either furrow or drip methods generally did not penetrate below 75 to 90 cm during any irrigation of the year, resulting in a gradual depletion of stored soil water during the two-year study. Soil water data suggests little or no potential for deep percolation losses in either drip or furrow plots. Observations in piezometers in several locations indicated no shallow groundwater to a depth of 360 cm at any measurement time.

Soil Profile Salt Accumulations: Chemical analyses of soil samples collected at intervals during the experiment have been largely completed, but have not been summarized at the time of this report.

FUTURE PLANS: After completion and testing of the newly installed drip lines in late spring of 1993 (installed at a depth of 25 to 27 inches (63 to 73 cm), a sudangrass crop will be planted as a cover crop for the spring and summer months. The alfalfa experiment will resume in the fall of 1993, with planting scheduled for October.

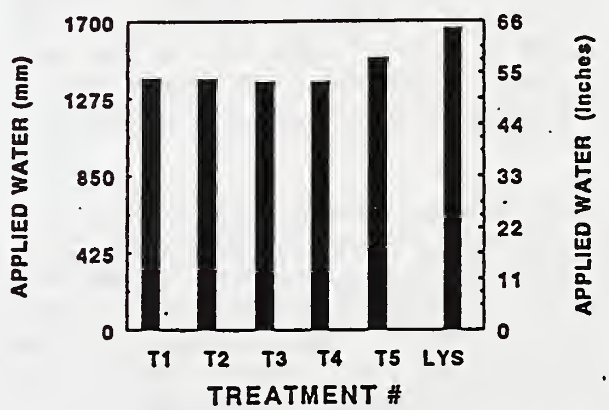


Figure 1. Applied water (mm and inches) during the 1992 season (January through November) in alfalfa irrigation treatments and lysimeter at Brawley, CA.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATION IN THE IMPERIAL VALLEY OF CALIFORNIA: FORAGE ALFALFA: FORAGE YIELDS

C.J. Phene, R.B. Hutmacher, R.M. Mead, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes, J. Rhoades, K.R. Davis, R.A. Schoneman, D. Dettinger, A. Bravo, M. Jones

OBJECTIVES: The alfalfa subsurface drip irrigation/furrow irrigation experiment at the Irrigated Desert Research Station in Brawley, CA, is a five-year evaluation of alfalfa water requirements and the long-term influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. This experiment focuses on the comparison of crop responses, irrigation water requirements, and salinity accumulations as affected by subsurface drip versus furrow irrigation. In addition, the influence of two drip lateral spacings will also be evaluated.

PROCEDURES: Treatments were as described in "Water management requirements of subsurface drip irrigation in the Imperial Valley: Operational Procedures" (elsewhere in this report). Treatments T1 through T4 were subsurface drip irrigation treatments and treatment T5 was furrow-irrigated.

RESULTS: *Crop Yields:* Although the possibility of differential harvest dates across irrigation treatments would have been allowed if necessary, in practice harvest dates across all 5 treatments have not varied by more than 5 days. The total number of hay harvests have been identical across treatments. Whitefly infestations were a problem in the late summer and fall of both 1991 and 1992 seasons, with a more significant impact on harvesting operations and hay quality (stickiness, fungal growth) in 1991. Although whitefly counts were not made in the alfalfa in 1992, no differences in whitefly infestations or severity of their effects on plants were noted across treatments.

Forage yields in January through November of 1992 averaged 15% lower in the furrow-irrigated plots when compared to the average across all drip irrigation treatments (Figure 1). No significant yield differences existed between treatments representing different types of drip tubing (T1 versus T2 and T3 versus T4). Average yields in the 80 inch lateral spacing treatments averaged 103% of average yields in the 40 inch lateral spacing plots. The yield differences between drip and furrow-irrigated treatments were greater in the establishment year (1991) than in 1992 (furrow 33% lower than drip in 1991).

Hay has been sampled from representative bales in all treatments during selected harvests during different times of the year. Analyses to date have not shown any consistent, significant differences in hay quality across treatments, but this question will be addressed more completely in the next phase of this alfalfa irrigation study.

FUTURE PLANS: After completion and testing of the newly installed drip lines in late spring of 1993 (installed at a depth of 25 to 27 inches (63 to 73 cm), a sudan grass crop will be planted as a cover crop for the spring and summer months. The alfalfa experiment will resume in the fall of 1993, with planting scheduled for October. Installation of the drip laterals at a greater depth should allow the irrigation system to be run at a much higher rate during the harvest cycle and avoid some of the water stress and slower regrowth occurring during that period.

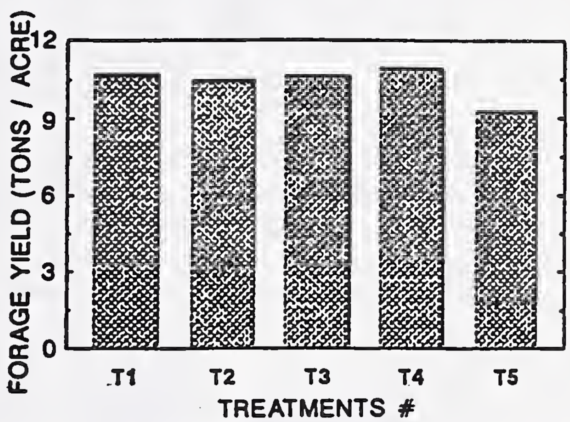


Figure 1. Total alfalfa yield (corrected to constant water content) from January through November of 1992 in alfalfa irrigation treatments at Brawley, CA.

UNIFORMITY EVALUATION OF SUBSURFACE DRIP IRRIGATION SYSTEMS AT USDA IRRIGATED DESERT RESEARCH STATION, BRAWLEY, CA

R. Yue, L. Kong, C.J. Phene, I-Pai Wu,
J.E. Ayars, R.B. Hutmacher, R. Mead

OBJECTIVES: To test and simulate the uniformity of subsurface drip irrigation systems at UC West Side Field Station, Five Points, CA.

METHODS: Two treatments, Plot 3, T2 and Plot 7, T4, were evaluated by both the Random-18-Point field test method and simulation models EGL, REGL and SBS in last November. The drip tube is RootGuard, which is buried 40 cm deep. Plot 3, T2 contains eight drip tubes. Plot 7, T4 has 4 drip tubes. Each treatment is about 31 ft wide and 525 ft long. The nominal emitter flow rate is 2 L/H at 18 to 20 psi. The water pressure at the inlet of mainline is 22 psi. The crop planted is alfalfa. Please refer to the earlier Research Progress Report for detail information on the systems.

PROCEDURES: Same as in "Uniformity Evaluation of Subsurface Drip Irrigation Systems at Britz Farm, Mendota, CA", of this report.

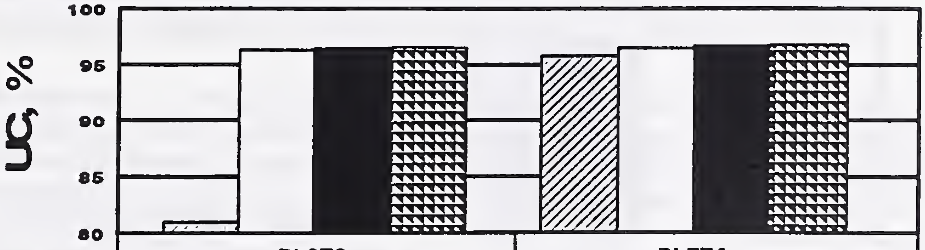
RESULTS: Figure 1 shows the results in terms of UC, CV and q_{var}. Figure 2 shows the differences between field tests and model simulations.

Plot 7, T4 has a very high uniformity coefficient of 95.77%. Plot 3, T2 has a measured UC as lower as 80.95%. The emitter flow rate data recorded there showed that three out of the eighteen emitters exposed inside Plot 3, Treatment 2, were partially plugged in different degrees.

The simulation results for Plot 7, T4 match the field test results, with less than 1% UC difference, and less than 2.5% CV difference. The model simulation results for Plot 3, T2 are about the same as the ones for Plot 7, T4. While, large differences in terms of UC, CV and q_{var} were obtained between model simulation results and field test results for Plot 3, T2, because the model simulations did not include the partial plugging.

The water samples taken at the end of the submains after the tests contained alfalfa tissues. Several leaks were found inside the subsurface drip treatments again later during the tests and were not repaired due to the limited time. Those un-repaired leaks affected the uniformity test results.

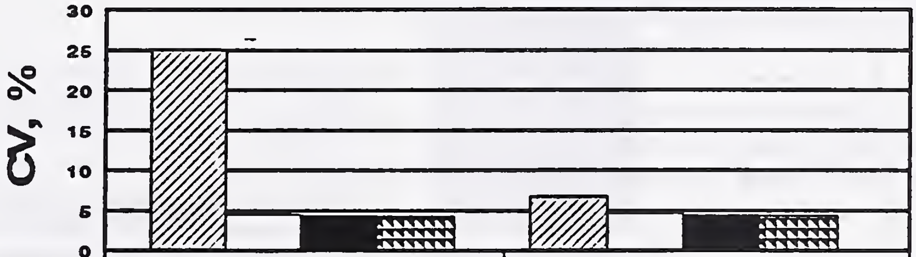
Results of Field Tests and Model Simulations
Brawley, RootGuard Tube, 160 m Tube Length



	PL3T2	PL7T4
Field Test	80.95	95.77
EGL	96.27	96.48
REGL	96.46	96.71
SBS	98.51	96.77

PL3T2: 8 tubes PL7T4: 4 tubes
Emitter Parameters: k=0.6912, x=0.5400, CV(M)=3%

Results of Field Tests and Model Simulations
Brawley, RootGuard Tube, 160 m Tube Length



	PL3T2	PL7T4
Field Test	25.04	6.78
EGL	4.55	4.67
REGL	4.33	4.41
SBS	4.27	4.35

PL3T2: 8 tubes PL7T4: 4 tubes
Emitter Parameters: k=0.6912, x=0.5400, CV(M)=3%

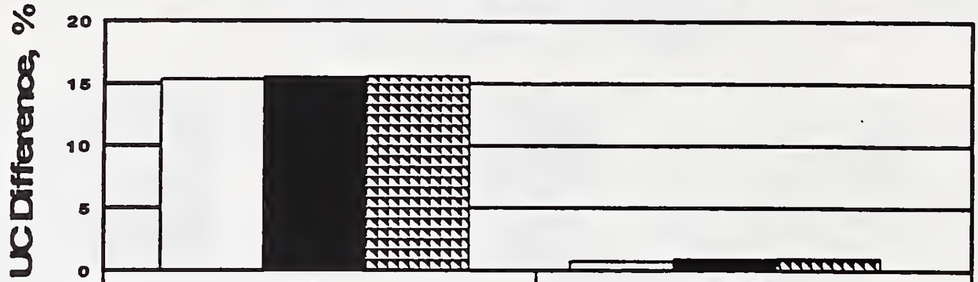
Results of Field Tests and Model Simulations
Brawley, RootGuard Tube, 160 m Tube Length

	PL3T2	PL7T4
Field Test	77.16	28.57
EGL	15.84	18.7
REGL	14.98	18
SBS	14.81	17.86

PL3T2: 8 tubes PL7T4: 4 tubes
Emitter Parameters: k=0.6912, x=0.5400, CV(M)=3%

Figure 1.

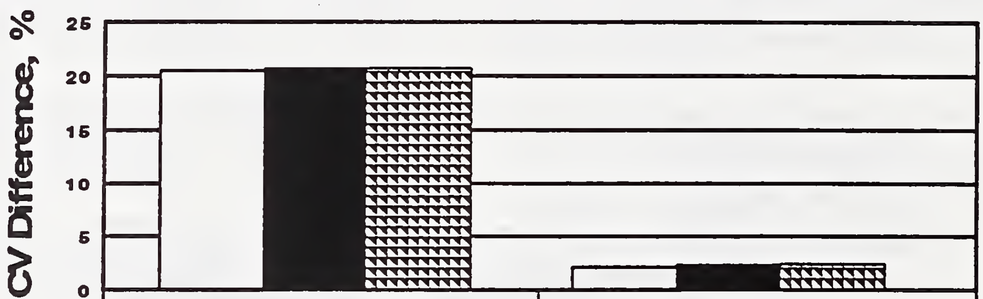
Difference Between Field Tests and Model Simulations
Brawley, RootGuard Tube, 160 m Tube Length



	PL3T2	PL7T4
EGL	15.32	0.71
REGL	15.51	0.94
SBS	15.56	1

PL3T2: 8 tubes PL7T4: 4 tubes
Emitter Parameters: k-0.6912, x-0.5400, CV(M)-3%

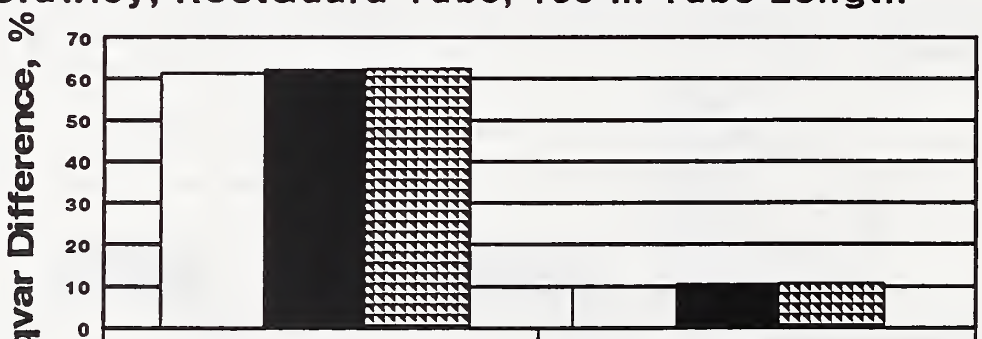
Difference Between Field Tests and Model Simulations
Brawley, RootGuard Tube, 160 m Tube Length



	PL3T2	PL7T4
EGL	20.49	2.11
REGL	20.71	2.37
SBS	20.77	2.43

PL3T2: 8 tubes PL7T4: 4 tubes
Emitter Parameters: k-0.6912, x-0.5400, CV(M)-3%

Difference Between Field Tests and Model Simulations
Brawley, RootGuard Tube, 160 m Tube Length



	PL3T2	PL7T4
EGL	61.32	9.87
REGL	62.18	10.57
SBS	62.35	10.71

PL3T2: 8 tubes PL7T4: 4 tubes
Emitter Parameters: k=0.6912, x=0.5400, CV(M)=3%

Figure 2.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATED CROPS IN THE IMPERIAL VALLEY: ROW CROP STUDY OPERATIONAL PROCEDURES FOR LETTUCE

C.J. Phene, R.B. Hutmacher, R.M. Mead, G. Cardon, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, S.S. Vail, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes, J. Rhoades, K.R. Davis, R.A. Schoneman, D. Dettinger, A. Bravo

OBJECTIVES: The row crop subsurface drip irrigation (SDI) project at the Irrigated Desert Research Station of the USDA-ARS in Brawley, CA is a five-year evaluation of water requirements of select annual crops and the long-term influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. The objectives of this experiment are to study and compare crop responses, irrigation water requirements, and salinity accumulations as affected by SDI systems. Initial plans were to include cantaloupe, processing tomatoes, cotton and lettuce in this study, but plans were altered considerably to lettuce, cotton and sweet onions due to the continued threat of white fly infestations plaguing the Imperial Valley since 1991.

PROCEDURES: *Drip Tubing / Field Layout*: Drip tubing with a wall thickness of 0.5 mm (Netafim, Inc., Typhoon type) was installed at a depth of 0.40 m below the soil surface in the center of each planting bed. Field F-3 of the Irrigated Desert Research Station in Brawley, CA was prepared with beds 1.52 m wide. Emitters on the drip laterals were spaced 1.02 m apart and are of a turbulent-flow design with a nominal output of 2 L h^{-1}. Each plot consists of six beds 80 m in length. There are four irrigation treatments with four replications in a randomized complete block design. Each irrigation treatment has electronic water meters and pressure transducers which can be continuously monitored using a data logger/computer control system accessible from the USDA-ARS-WMRL in Fresno or from other remote location. A fertilizer injection system consisting of a mixing tank and proportional flow injectors was used for N, P, and K injections through the SDI system. Sixteen access tubes were installed (one per plot) to allow soil water content measurements using neutron attenuation techniques.

A late-season lettuce variety ("Winterhaven") was planted, three rows per 1.52 m east-west bed on October 22, 1992. Pre-plant fertilizer (11-48-0) was applied at a rate of 76 kg ha^{-1} uniformly across all treatments. A total of 75 kg P ha^{-1} and 137 kg N ha^{-1} was applied throughout the season, with all fertilizer other than pre-plant applied through the drip system. The seed was germinated and the crop sprinkled up with 98 mm of water. During the period from planting through harvest, precipitation was 74 mm of rain fell.

Lettuce yields were determined from six hand-harvested 6.1 m sections of row in each plot, with all three rows per bed harvested separately , lettuce heads were counted and weighed untrimmed and trimmed. Yields were collected within the time frame that a commercial harvest would have been done based on head maturity. Soil samples were collected at the beginning and end of the lettuce experiment to characterize the influence of variable irrigation rates on accumulation of salts and chemical constituents in the soil profile.

Irrigation Control / Matric Potential System: Irrigation was controlled by a feedback system of twenty soil matric potential sensors installed in four blocks of one irrigation treatment (100% ET_c treatment, treatment #T3).

See additional report in this volume for specifics on experimental methodology and results from the soil matric potential sensor control and monitoring system.

RESULTS: Due to the mid-season planting date (mid-season for Imperial Valley lettuce plantings), whitefly pressure on the lettuce during the seedling stage was moderate and did not result in significant reductions in plant populations. The plant population problems that were noted in some plots were more related to problems in preparing a suitable seedbed due to problems with adequate incorporation of cotton plant residue from the cotton crop harvested in August.

FUTURE PLANS: The 1992-1993 lettuce crop was the second year of lettuce experiments in the continuing drip irrigation crop rotation experiment in the Imperial Valley. Work on other annual crops will continue. Serious mid- and late-season whitefly problems were encountered during the 1992 cotton cropping season, resulting in near total defoliation in the last weeks prior to harvest and considerable impact on results of the irrigation study. For this reason, cotton will not be planted in 1993, and the next crop will be sweet onions planted in the fall of 1993 (September or October). As with the lettuce crop, the soil matric potential sensor control system will be used in a feedback mode to schedule irrigation automatically.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATION IN THE IMPERIAL VALLEY: EVALUATIONS WITH LETTUCE

C.J. Phene, R.B. Hutmacher, R.M. Mead, G. Cardon, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, S.S. Vail, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes, J. Rhoades, K.R. Davis, R.A. Schoneman, D. Dettinger, A. Bravo

OBJECTIVES: The objectives of this experiment are to compare crop responses, irrigation water requirements, and salinity accumulations as affected by subsurface drip irrigation.

PROCEDURES: Details of experimental SDI system design and installation are given in the write up entitled: "Water Requirements of Subsurface Drip Irrigated Crops in the Imperial Valley: Row Crop Study Operational Procedures for Lettuce".

RESULTS: The soil matric potential control system was designed to apply 50% (T1), 75% (T2), and 125% (T4) of the water applied to treatment T3 (100%). The season total SDI-applied water in treatments T1, T2, T3, and T4 was 189 mm, 238 mm, 296 mm, and 324 mm, respectively. Some problems with the control system in November resulted in water applications in treatment T3 which were much higher than estimated ET_c during an 11 day period, so total water applications in all treatments were approximately 35 to 40 mm higher than planned and treatment differences in applied water were lower than planned.

Total seasonal water (sprinkler plus drip applied plus rainfall plus changes in soil profile water content) in treatments T1, T2, T3, and T4 were 331 mm, 344 mm, 377 mm, and 393 mm, respectively. Seasonal ETc estimates averaged 25 to 37 mm higher than in the lettuce subsurface drip treatments in the 1991-1992 experiments.

There was a significant influence of row location on average head weight (Table 1) and total lettuce yield per row (data not shown). Average lettuce heads in the northernmost row of each bed were significantly smaller in all irrigation treatments. There was no significant difference between southernmost and center rows. Soil sampling for gravimetric water content in 10 cm increments in the upper 100 cm of the soil profile under each of the rows on several measurement dates indicated slightly higher soil water contents under the center plant row only in the 30 to 50 cm depths, with no significant differences at any time at the other depths. Head growth in the southern rows was faster in the early season due to significantly warmer surface soil temperatures due to the southern sun exposure in those rows. With this desire for head uniformity in mind, most commercial growers attempt north-south row orientation when growing lettuce. This was not possible in this experiment because the drip tubing was already installed in an east-west direction.

Lettuce yields were significantly higher in the 100% ET_c treatment (T3) than in the other treatments (Table 1), at a season total water use of 15.5 inches. This is approximately 75 to 85% of the typical mid-season lettuce water application under surface irrigation methods in the Imperial Valley.

FUTURE PLANS: Other annual crops will be grown on this field to further evaluate the drip irrigations system and use of the matrice potential-based irrigation control system. Long-term evaluations will also focus on soil salinity profiles developing with long-term use of moderately saline water in drip irrigation. A sweet onion crop will be planted in fall of 1993.

Table 1. Lettuce yields (fresh weight) and average head weight in subsurface drip irrigation treatments in Brawley, CA in 1992-1993 experiment.

Irrigation treatment	Row location on each bed	Average head weight (kg)	Lettuce fresh weight (Mg ha^{-1})
T1	North	0.54	30.3 b†
	Center	0.61	41.9 a
	South	0.65	41.9 a
	average*	0.60	37.9
T2	North	0.51	30.5 c
	Center	0.67	46.1 a
	South	0.61	35.9 b
	average*	0.59	37.5
T3	North	0.57	38.7 b
	Center	0.72	51.6 a
	South	0.69	44.9 a
	average*	0.66	45.1
T4	North	0.54	35.5 b
	Center	0.64	43.3 a
	South	0.65	34.2 b
	average*	0.61	37.7

* Indicates average yield including north, center, south rows on beds of respective treatments.
† Means within an irrigation treatment followed by different letters were significantly different at the 5% level by the Duncan's Multiple Range Test.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATION IN THE IMPERIAL VALLEY: ROW CROP STUDY OPERATIONAL PROCEDURES FOR COTTON

C.J. Phene, R.B. Hutmacher, R.M. Mead, G. Cardon, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, S.S. Vail, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes, J. Rhoades, K.R. Davis, R.A. Schoneman, D. Dettinger, A. Bravo

OBJECTIVES: The row crop subsurface drip irrigation project at the Irrigated Desert Research Station of the USDA-ARS in Brawley, CA is a five-year evaluation of water requirements of select annual crops and the long-term influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. This experiment focuses on the comparison of crop responses, irrigation water requirements, and salinity accumulations as affected by subsurface drip irrigation. Initial plans were to include cantaloupe, processing tomatoes, cotton and lettuce in this study, but plans were altered considerably to lettuce, cotton and sweet onions due to the continued threat of white fly infestations plaguing the Imperial Valley since 1991.

PROCEDURES: Drip tubing / field layout: Drip tubing with a wall thickness of 20 mil (Typhoon type, Netafim, Inc.) was installed at a depth of 40 cm below the soil surface in the center of each planting bed. The F-3 field of the Irrigated Desert Research Station in Brawley, CA was prepared in beds 1.52 m wide. Emitters on the drip laterals were spaced 1.02 m apart and are of a turbulent-flow design with a nominal output of 2 L h^{-1}. Each plot consists of six beds 80 m in length. There are four irrigation treatments with four replications in a randomized complete block design. Each irrigation treatment has electronic water meters and pressure transducers which can be continuously monitored using a data logger/computer control system accessible through the USDA-WMRL in Fresno or other remote location. A fertilizer injection system consisting of a mixing tank and proportional flow injectors was used for N, P, and K injections through the drip irrigation system. Sixteen access tubes were installed (one per plot) to allow soil water content measurements using neutron attenuation techniques.

Cotton (var. DPL5461) was planted on March 23, 1992 in field F-3, with two planted rows per 1.52 m bed. The planted rows were equidistant from the subsurface drip irrigation line, which was 40 cm below the average soil surface at the center of each bed. The subsurface drip system used in the same as described previously in this volume ("Water Management Requirements of Subsurface Drip Irrigation in the Imperial Valley: Row Crop Study Operational Procedures for Lettuce").

About 33 kg N per ha was applied pre-plant as urea, and 13 kg of P per ha broadcast-applied as superphosphate at planting. All other fertilizer was applied through the drip system using a proportional injection pump system. Total P and N applied to the crop (drip-applied plus pre-plant) was 66 kg P per ha and 183 kg N per ha. An average plant population of approximately 96,000 plants per ha was achieved. Temik was applied for early-season insect control at recommended rates for cotton. For germination and early growth, about 50-55 mm of water was applied by sprinklers, with all irrigation treatments receiving similar application amounts. Total rainfall from planting through late July was 56 mm. Soil samples were collected at the initiation of the cotton experiment and will be collected at the conclusion to determine irrigation treatment impacts on soil salinity profiles across the beds and with depth.

Treatment T3 was the treatment to which all other treatments were keyed since it was used as part of a unique irrigation control method which was investigated in this experiment. The irrigation control system consists of a group of field-installed commercial soil matric potential sensors installed at a fixed distance from the subsurface drip emitters. The sensors are connected through a communications system to a data logger which controls the pump/solenoid irrigation control for field F3. Irrigation treatments were initiated on calendar day 143, and between day 143 to 162, treatment T1, T2, T3, T4 received 60%, 80%, 100%, and 120%, respectively, of the amounts applied to treatment T3. From day 163 through termination of irrigation on day 225, treatment T1, T2, T3, T4 received 50%, 75%, 100%, and 125% of the amounts determined for T3. Total seasonal water applications ranged from 389 mm to 1047 mm across treatments.

Plant water status was monitored twice weekly using an infrared thermometer in all treatments. Plant height, growth and boll development were monitored biweekly in all treatments. Seed cotton yields were determined from four 6.1 m sections of hand-harvested beds per plot, with both rows per bed harvested.

RESULTS: Planting and irrigation treatments proceeded according to schedule throughout the season. Plant populations were acceptable in all plots. Sub-sampling in measurements made in all plots was initiated in late May, with subsamples separated according to east versus west halves of each plot. This separation was done based on observations of more severe whitefly infestations typically occurring on the east side of the plots when compared to the west. There was some evidence that whiteflies first moved into the cotton from the alfalfa field immediately adjacent and to the east of the cotton.

FUTURE PLANS: The 1992 cotton crop was the second year of annual crop experiments in the continuing drip irrigation crop rotation experiment in the Imperial Valley. Work on other annual crops will continue. Serious mid- and late-season whitefly problems were encountered during the 1992 cotton cropping season, resulting in near total defoliation in the last weeks prior to harvest and considerable impact on results of the irrigation study. For this reason, cotton was not planted in 1993, and the next crop will be sweet onions planted in the fall of 1993 (September or October). As with the lettuce crop, the matric potential sensor control system will be used to determine irrigation scheduling.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATION IN THE IMPERIAL VALLEY: ROW CROP STUDY - COTTON WATER USE AND YIELDS

C.J. Phene, R.B. Hutmacher, R.M. Mead, G. Cardon, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, S.S. Vail, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes, J. Rhoades, K.R. Davis, R.A. Schoneman, D. Dettinger, A. Bravo

OBJECTIVES: The row crop subsurface drip irrigation project at the Irrigated Desert Research Station of the USDA-ARS in Brawley, CA is a five-year evaluation of water requirements of select annual crops and the long-term influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. This experiment focuses on the comparison of crop responses, irrigation water requirements, and salinity accumulations as affected by subsurface drip irrigation. Initial plans were to include cantaloupe, processing tomatoes, cotton and lettuce in this study, but plans were altered considerably to lettuce, cotton and sweet onions due to the continued threat of white fly infestations plaguing the Imperial Valley since 1991.

PROCEDURES: The field layout, drip irrigation system, and basic cultural operations and plant measurements were described previously in "Operational Procedures" description of this experiment elsewhere in this volume. In addition, in cooperation with the USDA-ARS Cotton Research Laboratory in Phoenix, AZ, leaves were sampled at intervals during the season to evaluate the influence of irrigation treatments and plant water stress on whitefly infestations and resulting plant damage. Results of these investigations were not all available at the time of this report and will not be summarized here. Additional information on the whitefly results will be available from one of the authors at a later date.

RESULTS: Estimates of total season soil water depletion ranged from 182 mm in treatment T1 to less than 40 mm in treatment T4. Significant deep percolation was estimated to occur in treatment T4, in amounts ranging from 57 to 88 mm across blocks. Estimates of crop evapotranspiration ranged from a low of 660 mm in T1 to over 950 mm in T3 and T4.

Water application amounts based on the soil matric potential sensors were compared to estimated ETc calculated using grass reference ET_o (measured using data from a CIMIS-type weather station on-site) in combination with a modified, conservative crop coefficient determined using multiple years of data from the San Joaquin Valley. The crop coefficient was modified to account for faster early-season heat unit accumulation in the Imperial Valley. In general, estimated ET_c using this conservative crop coefficient fell about midway between the accumulated applied water of treatment T2 and T3.

Based on relative differences in mid-season to late-season growth and boll counts within the different irrigation treatments, it was expected that significant yield differences would be observed across treatments. Mid-season plant water stress levels in treatments T1 and T2, as indicated by Crop Water Stress Index (CWSI) values in excess of 0.4 and 0.2, respectively, were significantly worse than in T3 and T4. The more severe water stress levels of T1 would have been expected to reduce seedcotton yields and plant growth. As yield data shown in Table 1 indicates, this was not the case in 1992. Early-season boll set was good on all treatments, and this was probably significant in maintaining relatively good lint yields in the low irrigation treatments (T1, T2). Mid- to late-season boll retention and maturation were strongly influenced by the severe whitefly infestation which dominated the field during June and July. Apparently, the severity of the infestation and accompanying partial to total defoliation brought on by whitefly injury was sufficient to abort bolls or restrict late-season boll development.

Petiole NO_3-N, PO_4-P, and K levels were within levels considered adequate in all plots and were not significantly different across treatments prior to the whitefly infestations. Treatment T4 generally exhibited excessive vegetative growth which is usually detrimental to boll retention and high yields. While not statistically different, yields in T4 were actually closer to yields in treatment T1, the low water application treatment. Total above ground plant dry matter and leaf area increased with increasing water applications.

Table 1. Seed cotton and lint yields for cotton in Brawley subsurface drip experiment in field F3 during March through August, 1992.

Irrigation	Seed cotton yields		Lint cotton yields	
treatment	(kg ha^{-1})	(lbs ac^{-1})	(kg ha^{-1})	(lbs ac^{-1})
T1	2707*	2415	1088	971
T2	3215	2868	1310	1169
T3	3137	2799	1290	1151
T4	2861	2553	1184	1056

* There were no significant differences in yield components across irrigation treatments by Randomized Complete Block Analysis under Orthogonal Comparisons.

LYSIMETER MEASUREMENTS OF EVAPOTRANSPIRATION IN MATURING PEACH TREES

C.J. Phene, S. Johnson, D. Clark, R.M. Mead, and P. Wiley

OBJECTIVES: To use a computerized weighing lysimeter system for determination of evapotranspiration of maturing peach trees and to control micro-irrigation systems in a real time feedback mode at several evapotranspiration rates in the research site surrounding the lysimeter. To produce a set of crop coefficient functions for years two through six for use with CIMIS to schedule irrigation of peaches in the San Joaquin Valley.

PROCEDURES: (For details about lysimeter design and instrumentation see 1986 through 1991 reports). The lysimeter (including the water in its irrigation tanks) was weighed hourly to determine the evapotranspiration (ET_c) of the two trees; the mass loss of the lysimeter was compared to a threshold mass of 96 kg (8 kg = 1 mm ET_c) and after 12 mm (96 kg) of ET_c was measured the lysimeter was irrigated until the threshold mass was met. At midnight each day, the water tanks were refilled to a pre-set level; the flow of water was measured electronically with a flowmeter and the new lysimeter mass was used as the baseline mass for the next day.

Daily outputs from the lysimeters were transmitted automatically via telecommunication to the Water Management Research Laboratory microcomputer and basic data were stored on a hard disk and backed up on high density floppy disks.

RESULTS: Table 1 shows monthly simmaries of rainfall, lysimeter ET_c grass reference ET_o (CIMIS), the lysimeter and actual tree crop coefficients (K_c's), and the number of lysimeter irrigations.

Figure 1 shows the daily reference ET_o and the peach tree evapotranspiration calculated for the total area occupied by a tree (not the lysimeter area). Figure 2 shows the crop coefficients for nearly mature peach trees; the lysimeter calculated K_c is on the left axis and the actual tree K_c is on the right axis. Figure 3 shows the integrated crop coefficients for the tree from 1988 through 1992. These curves were generated by daily calculations of the cumulative ET_c and ET_o data and taking the ratio of the slope of the ET_c and ET_o curves. As discussed in previous reports the K_c tracks evapotranspiration and hence its accuracy in predicting ET_c is limited to ± 10%, especially on a daily basis. Each tree used approximately 9812 L of water. Reference ET_o was 1298 mm. There were 189 irrigations, totaling 2268 mm of applied water and 368 mm of rainfall. No drainage was collected from the lysimeter. The two trees in the lysimeter grew to a size approximately equal to the size of the trees in the surrounding orchard.

FUTURE PLANTS: This experiment will be continued until the peach trees reach a fully mature stage.

Table 1. Monthly totals of rainfall, peach tree ET_c (lysimeter), reference ET (Et_o, CIMIS) lysimeter and peach tree K_c's, and number of irrigations.

Month	Rain (mm)	ET_c Lysimeter (mm)	CIMIS(ET_o) (mm)	Lysimeter K_c	Actual K_c (8.91 m^2 /tree)	# of Lysimeter Irrigations
Jan	49	6	21	0.26	.117	0
Feb	108	25	54	.46	.207	0
March	33	50	91	.55	.248	0
April	13	165	148	1.12	.504	13
May	15	328	187	1.75	.788	27
June	1	386	191	2.03	.914	33
July	0	460	155	2.33	1.05	38
Aug	0	445	181	2.46	1.11	37
Sept	0	329	127	2.58	1.16	28
Oct	59	209	81	2.57	1.16	13
Nov	3	39	39	.99	.44	0
Dec	8	11	23	.49	.22	0
Total	368	2453	1298			189

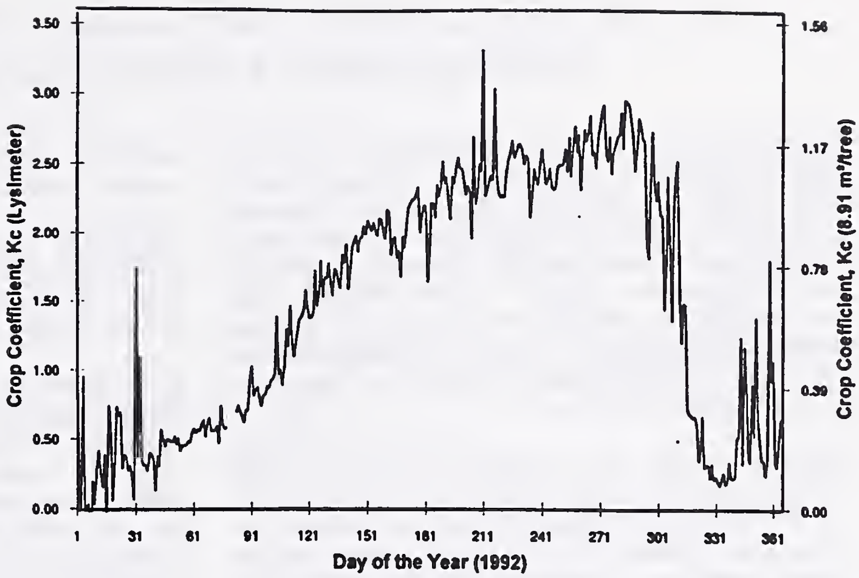


Figure 1. Daily reference ET (ET_o, CIMIS) (left axis) and daily peach tree evapotranspiration (8.91 m^2/tree (right axis) for nearly mature peach trees.

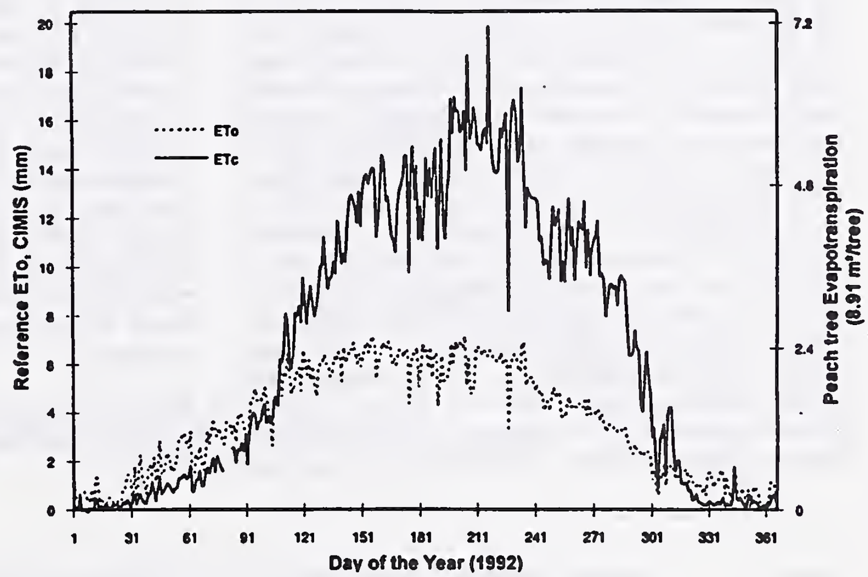


Figure 2. Crop coefficients of nearly mature peach trees based on lysimeter area (left axis) and actual area occupied by each peach tree (right axis).

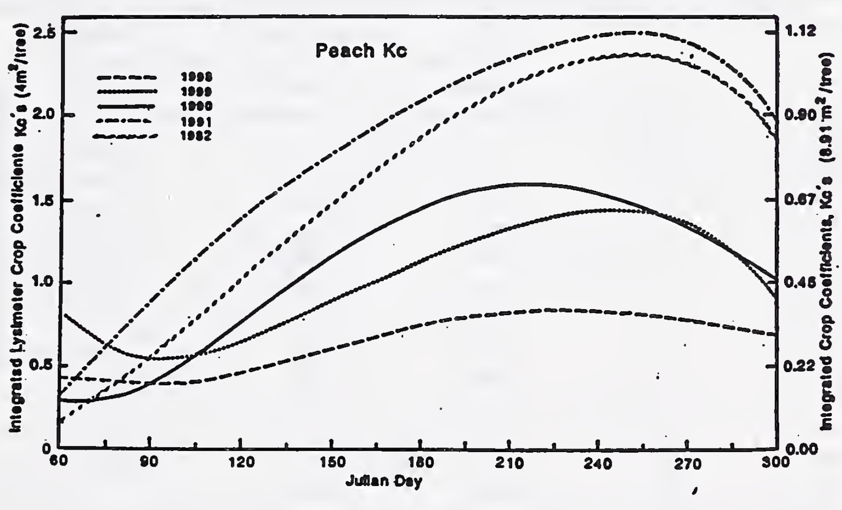


Figure 3. Integrated crop coefficients K_c's for nearly mature peach trees planted in 1987 (lysimeter area, left axis and actual area, right axis).

LYSIMETER MEASUREMENTS OF EVAPOTRANSPIRATION IN MATURING GRAPES

C.J. Phene, L. Williams, D. Clark, R.M. Mead, and P. Biscay

OBJECTIVES: To use a computerized weighing lysimeter system for determination of evapotranspiration and crop coefficient (K_c) of drip irrigated grapes; to control in a real time feedback mode surface and subsurface drip systems at several evapotranspiration rates in the research site surrounding the lysimeter; to produce a set of crop coefficient functions for years two through six for use with CIMIS to schedule irrigation of grapes in the San Joaquin Valley.

PROCEDURES: The lysimeter (see 1987 through 1991 annual reports for details), including the water in the tanks, was weighed hourly to determine the evapotranspiration (ET_c) of the two grapevines; the mass change was compared to a threshold mass of 16 kg (8 kg - 1 mm ET_c) and after 16 kg of mass loss the lysimeter was irrigated until the threshold mass was met. At midnight each day, the water tanks were refilled to a pre-set level; the volume of water was measured with an electronic flowmeter and the lysimeter mass was used as the baseline mass for the next day. Daily crop coefficients (K_c) were calculated by taking the ratio of ET_c/ET_o where ET_o is the grass reference evapotranspiration. Reference crop ET (ET_o) was calculated from data collected at a CIMIS weather station located at the Kearney Ag Center, approximately 325 m from the Thompson Seedless vineyard used in the study. Soil water content was measured with a Troxler Model 3332 Depth Moisture Gauge (neutron probe). Daily sensor outputs from the lysimeter were transmitted via telecommunication to the WMRL microcomputer and basic data were stored on a hard disk and backed up on high density floppy disks.

RESULTS: Table 1 shows monthly summaries of rainfall, lysimeter ET_c, the reference evapotranspiration (ET_o), the lysimeter K_c, the actual vine K_c, and the number of lysimeter irrigations.

Figure 1 shows the daily reference ET_o and the vine evapotranspiration calculated for the total area occupied by a vine (not the lysimeter area). Figure 2 shows the crop coefficients for mature Thompson seedless vines; the lysimeter calculated K_c is on the left axis and the actual vine K_c is on the right axis. Figure 3 shows the integrated crop coefficients for the vine from 1988 through 1992. These curves were generated by daily calculations of the cumulative ET_c and ET_o data and taking the ratio of the slope of the ET_c and ET_o curves. As discussed in previous reports, the K_c tracks evapotranspiration and hence its accuracy in predicting ET_c is limited to ± 10%, especially on a daily basis. Each vine used approximately 6632 L of water. Reference ET_o was 1298 mm. There were 696 irrigations, totaling 1372 mm of applied water and 368 mm of rainfall. No drainage was collected from the lysimeter. The two vines in the lysimeter grew to a size approximately equal to the size of the vines in the surrounding vineyard.

FUTURE PLANTS: This experiment will be continued until the peach trees reach a fully mature stage.

Table 1. Monthly totals of rainfall, grapevine ET^c (lysimeter), reference ET (Et_o, CIMIS), lysimeter and grapevine K_c's, and number of irrigations.

Month	Rain (mm)	ET_c Lysimeter (mm)	CIMIS(ET_o) (mm)	Lysimeter K_c	Actual K_c (7.52 m^2/vine)	# of Lysimeter Irrigations
Jan	49	9	21	0.44	0.23	0
Feb	108	30	54	0.54	0.29	0
March	33	53	91	0.12	0.06	0
April	13	93	148	0.61	0.33	2
May	15	230	187	1.22	0.65	106
June	1	314	191	1.65	0.88	157
July	0	335	155	1.70	0.91	167
Aug	0	295	181	1.63	0.87	147
Sept	0	166	127	1.21	0.65	83
Oct	59	74	81	0.89	0.47	34
Nov	3	29	39	0.74	.39	0
Dec	87	30	23	0.91	0.49	0
Total	368	1658	1298			696

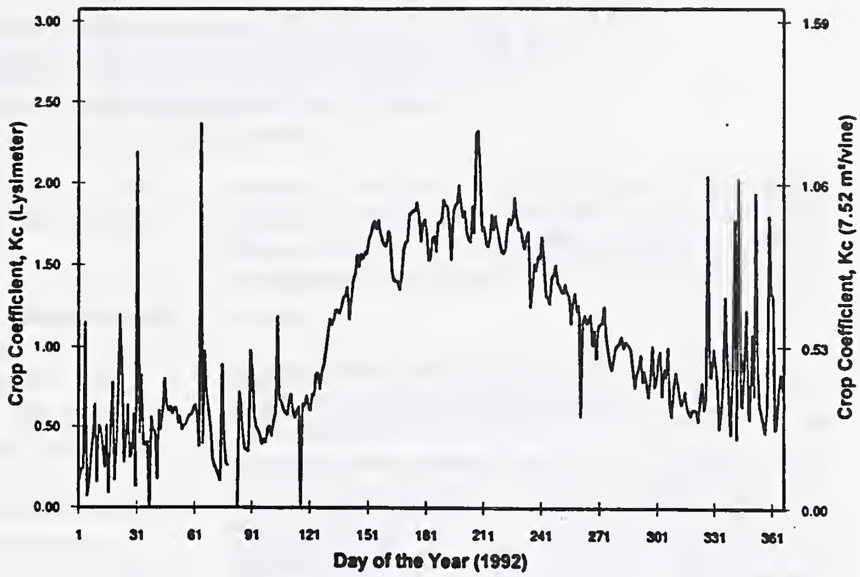


Figure 1. Daily reference ET (ET_o, CIMIS) (left axis) and daily vine evapotranspiration (7.52 m^2/vine (right axis) for nearly mature Thompson Seedless vines.

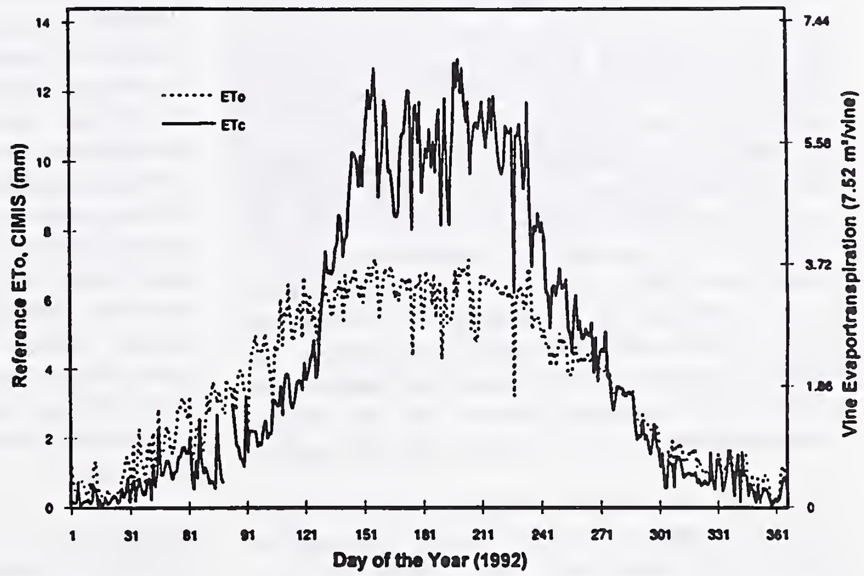


Figure 2. Crop coefficients of nearly mature Thompson Seedless vines based on lysimeter area (left axis) and actual area occupied by each vine (right axis).

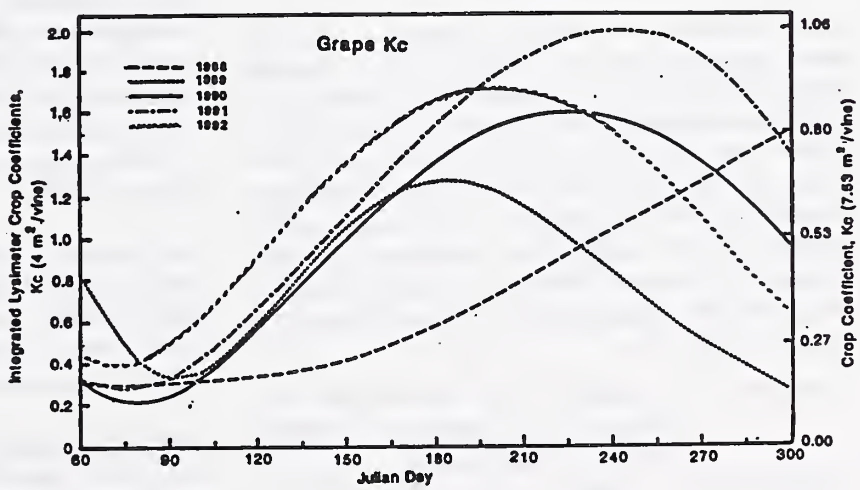


Figure 3. Integrated crop coefficients K_c's for nearly mature Thompson Seedless vines planted in 1987 (lysimeter area, left axis and actual area, right axis).

CONTROLLING GROWTH OF SUBSURFACE DRIP-IRRIGATED COTTON WITH PRECISE PIX INJECTION IN THE IRRIGATION WATER

R.B. Hutmacher, G.S. Bañuelos, S.S. Vail,
S. Zambrzuski, S. Downey

OBJECTIVE: To evaluate the effect, if any, on cotton growth of different concentrations and frequencies of PIX applied through a subsurface drip system.

PROCEDURE: Cotton (VAR. Maxxa) was planted during 1992 (JD 114) in a Panoche Clay loam soil at the University of California West Side Field Station. The treatments were arranged in a randomized complete block design. The plot area consisted of four replicates of nine treatments. Each plot consisted of 12 rows spaced 0.76 m apart and approximately 10 m in length. Prior to planting, subsurface drip irrigation laterals were shanked into the field at a depth of 45 cm below the average soil surface, with the laterals placed in alternate furrows for a total of six per plot. In-line turbulent-flow emitters were used, with a flow rate of 4 L/h, spaced 0.9 - 1 m apart along each lateral. All plots were irrigated with subsurface drip, operated to apply approximately 1 mm per irrigation. Irrigation was applied as needed to replace 100% of estimated crop evapotranspiration (ET_c). The ET_c was calculated using a crop coefficient (K_c) (developed in 1988 during previous cotton subsurface drip experiments at the WSFS) in conjunction with grass reference evapotranspiration determined on-site at the weather station installed by the WMRL at the field station.

Phosphoric acid, calcium ammonium nitrate (CAN-17), and potassium nitrate fertilizers were applied through the subsurface drip system using a Hutchings® injection pump system.

Both irrigation and fertilizer application amounts were monitored on a weekly basis. Growth regulator treatments of mepiquat chloride (PIX) (applied between JD 181-213, 1992) consisted of a control (T#9, no PIX); 2 foliar application treatments (@ 1 pint/acre rate, .62% PIX) at 2 different frequencies (T#7, 1 x; T#8, 2 x per season); and 6 subsurface drip application treatments (applied through a Dosatron® injector @ 1:200 dilution) using different combinations of concentration and frequency (T#1-6).

Treatment #1: ≈ .0056% PIX between day 181 through 183; thereafter, ≈ .0495% (total of 7 applications).

Treatment #2: ≈ .006% PIX (JD 181-192); thereafter, ≈ .046% (total of 11 applications).

Treatment #3: ≈ .0059% PIX (JD183-192); thereafter, ≈ .043% PIX (total of 10 applications).

Treatment #4: ≈ .011% PIX (JD 181-192), thereafter, ≈ .093% PIX (Total of 7 applications).

Treatment #5: ≈ .01% PIX (JD 181-192); thereafter, .096% (total of 11 applications).

Treatment #6: ≈ .063% PIX (JD 181-192); thereafter, ≈ .463% (total of 11 applications).

The following parameters were measured during the season: plant height, node counts (main stem and vegetative), number of fruiting branches, number of bolls/plant, percentage of bolls by position, and petiole samples (analyzed for nitrates, potassium, and phosphates) were monitored throughout the growing season. Soil moisture, total applied water and leaf water potentials were also monitored. Canopy temperature and psychrometer data were collected weekly to determine crop water stress index (CWSI) values. Several destructive plant samplings were taken to determine concentrations of PIX in various plant tissues. Harvest was on JD 301, and seed cotton yield, percentage of lint, and lint yield were determined.

RESULTS: Plant height measurements were significantly effected by the foliar applications only (TRT #7 and #8) on the average 17% lower than all other treatments. Number of main stem nodes on averages were 6% lower for TRT #7 and #8 as compared with the other treatments. The total season drip irrigation amounts averaged 755 mm for all treatments, with an $\bar{x}$ soil water depletion of ≈ 160* m,giving a total $\bar{x}$ water use of ≈ 915* mm (zero rainfall).

Seed cotton yields averaged 7173.7 kg/ha, with the only significant differences between TRT #5 (low) and #6 (high). The average percentage of lint was 39.45%, the average lint yield 2865.52 kg/ha, with no significant treatment differences.

FUTURE PLANS: Changes will be made in timing, rate, and concentrations of PIX applications experiment will be relocated to an adjacent larger field as part of a N study beginning April 1993 at the West Side Field Station.

NORTH LYSIMETER AND SDI FIELD UPDATE

K.R. Davis, C.J. Phene, R.B. Hutmacher, R.Mead, S.Vail,
M. Peters, D. Clark, D. Ballard, and N. Hudson

OBJECTIVES: To update activities on north lysimeter field (Field 27).

PROCEDURES: During the winter 1990–1991 subsurface drip irrigation (SDI) laterals were shanked into two–thirds of the existing beds of the north lysimeter field (Field 27) at the University of California West Side Field Station. The remaining beds consisted of the original SDI plots installed at 45 cm depth in 1984. (See various Annual Reports and publications.) The SDI laterals were installed in the center of 163–cm wide beds and at depths of 60 cm (old high–frequency surface drip [HFSD] plots) and 30 cm (old low–frequency surface drip [LFSD] plots). The dripline (DL) installed was of the in–line emitter type (GEOFLOW, Rootguard) with a nominal flow rate of 4 l/hr at 18 PSI and a spacing of 0.9 m.

The field plots were fallow during 1991. Retrofit construction began in October, 1991. Existing PVC mainlines and submain risers were located and exposed. Trenches were excavated inside of the existing mainlines and plot submains were constructed and connected to the mainlines. Also, at the ends of each plot, flushout manifolds were installed.

During 1992 the field plots and crop lysimeter were planted to wheat and managed uniformly.

RESULTS: After field modifications, fallow, and uniform cropping, the north lysimeter field was prepared for future use. These field plots have SDI place–ment depths of 30, 45, and 60 cm as major treatments with four replications.

FUTURE PLANS: The pump station will be re–constructed in 1993 to include new centrifugal irrigation pump, sand–media filter, screen filter, flow–sensing proportioning pump, and 9–section meter/valve headwork manifold. The field plots and crop lysimeter will be used for research in 1993.

DRIP LATERAL INSTALLATION DEPTH: EFFECTS ON CROP GROWTH, YIELD, NUTRIENT UPTAKE AND SOIL WATER AND SALINITY DISTRIBUTION

R.B. Hutmacher, C.J. Phene, K.R. Davis, D.A. Clark, M. Rehan, C.A. Hawk, M.S. Peters, D. Ballard, N. Hudson, A. Bravo

OBJECTIVES: Determine the influence of subsurface drip lateral installation depth on: (a) growth and yield of cotton and other crops; (b) salinity and water distribution within the soil profile relative to emitter locations; and (c) crop nutrient uptake and applied nutrient distribution within the soil profile.

PROCEDURES: Early in 1992, drip tubing with in-line emitters was installed at depths of 30, 45, and 60 cm (12, 18, 24 inches, respectively) with uniform 64 inch lateral spacing. Drip lines were installed below the center of each 64 inch bed. Each lateral installation depth treatment consisted of 10 beds per plot, replicated 4 times. This field already is the site of an in-ground weighing lysimeter which can be used to monitor crop water use and can control field irrigation. A new pump, media and screen filters, proportional flow fertilizer injection system, and electronic water meters and pressure transducers will allow more complete control and automated monitoring capabilities. Irrigation water will come from the California Aqueduct and/or from a moderately saline deep well, with the source depending on 1993 water allotments in the Westlands Irrigation District.

Within each installation depth treatment, there was a further subdivision of three secondary treatments of 3, 3, and 4 beds each within each replication. These secondary treatments will allow consideration of water application amount and fertility treatments in addition to the lateral installation depth treatments.

During the 1993 season, cotton was grown on this field and the three secondary treatments consisted of different application treatments of the plant growth regulator "PIX" (mepiquat chloride). The liquid growth regulator was injected into the irrigation water during a 10 mm irrigation, followed up within one to two hours with another 8 mm application of irrigation water to dilute and move the growth regulator out from the point of application into the root volume. Application rates of 0 L ha−1, 21.9 L ha−1, and 36.6 L ha−1 will be tested in 1993, with these application rates based on preliminary results from a 1992 study (see "Controlling growth of subsurface drip irrigated cotton with precise PIX injection in the irrigation water" elsewhere in this volume).

Plant growth, development and yields will be monitored to evaluate the effects of drip lateral installation depth and PIX treatments. Plant water status will be monitored using infrared thermometer techniques. Petiole nutrient status will be monitored weekly and above-ground plant samples will be collected, separated into component parts, and ground for analysis of nutrient uptake several times during the growing season.

RESULTS / FUTURE PLANS: Drip tubing installation was completed in 1992. A grid of 9 matric potential sensors will be installed in spring of 1993 at one field location within each lateral installation depth treatment in order to monitor soil matric potential as a function of depth and distance from drip emitters. Completion of the pump and manifold control system for water and fertilizer application is scheduled for completion during late spring/early summer of 1993. A cotton crop will be planted in April, 1993 and crop growth parameters, nutrient status and yield responses will be monitored.

The influence of depth of lateral installation on soil water, nutrient and salt distribution will be determined using a combination of in-situ soil sensors and chemical analyses of soil samples collected a minimum of three times (early-season, late-season, post-season).

UNIFORMITY EVALUATION OF SUBSURFACE DRIP IRRIGATION SYSTEMS AT UC WEST SIDE FIELD STATION, FIVE POINTS, CA

R. Yue, L. Kong, C.J. Phene, J. E. Ayars, I-Pai Wu, K. Davis

OBJECTIVES: To test and simulate the uniformity of subsurface drip irrigation systems at UC West Side Field Station, Five Points, CA.

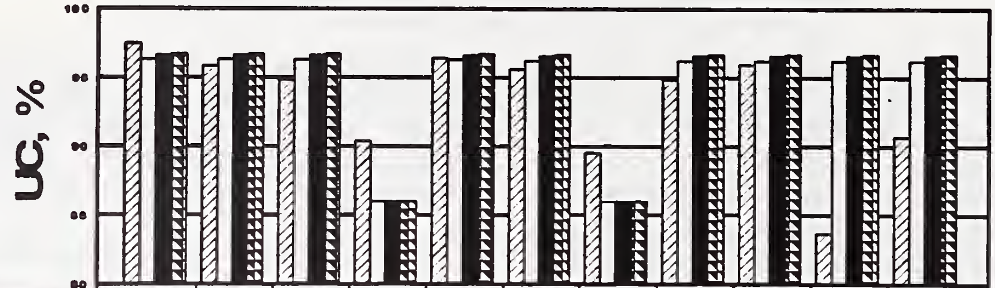
PROCEDURES: The original subsurface drip systems was installed in 1984 and consisted of Agrifim In-Line turbulent emitters. In April, 1989, eight P0 laterals in replications 1 (PI2P0) and 2 (PL4P0) were replaced with Agrifim "RootGuard" In-Line turbulent flow emitters. The drip tube installation depth was 18 inches, and the nominal emitter flow rate was 4 L/H. Water pressure at inlet of the mainline is 24 psi. The submain units are either 16.5 ft (P1 and P2) or 22.0 ft (P0) wide, and 298 ft long. Each unit contains 3 (P1s or P2s) or 4 (P0s) drip tubes. Please refer to earlier Annual Report, or Davis, K.R. et. al., "Trickle Frequency and Installation Depth Effects on Tomatoes", Proceedings of the Third International Drip/Trickle Irrigation Congress, Fresno, CA, 1985, for detail information. Eight submain units were evaluated by both the Random-18-Point field test method and simulation models EGL, REGL and SBS during September and October, 1992.

The same testing procedures was used as in "Uniformity Evaluation of Subsurface Drip Irrigation Systems at Britz Farm, Mendota, California", of this report.

RESULTS: Figure 1 shows the results in terms of UC, CV and q_{var}. Figure 2 shows the differences between field tests and model simulations. If a submain unit has a higher UC, it will have a lower CV or q_{var}.

Most of the field tested UCs and the model simulated UCs are above 95%. This proves that the drip systems perform very well even after nine years, and model simulation results match the field test results, with 6% maximum UC differences if all the leaks are repaired. One emitter out of the nineteen emitters dug out in Plot 11, P0 was totally plugged; one emitter out of the nineteen emitters dug out in Plot 11, P1 was almost totally plugged. Both leaks and emitter plugging affect the performance of drip irrigation systems significantly. The UC of Plot 11, P0 dropped from 96% to 90% based on the field test results, to 86% based on the model simulation results, if one out of every nineteen emitters is plugged. The tested UC would drop from 91% to 84% if leaks were not repaired in Plot 11, P2. Hydraulic design, manufacturing variation, emitter plugging, temperature, leaks are the important factors that affect the performance of drip irrigation systems.

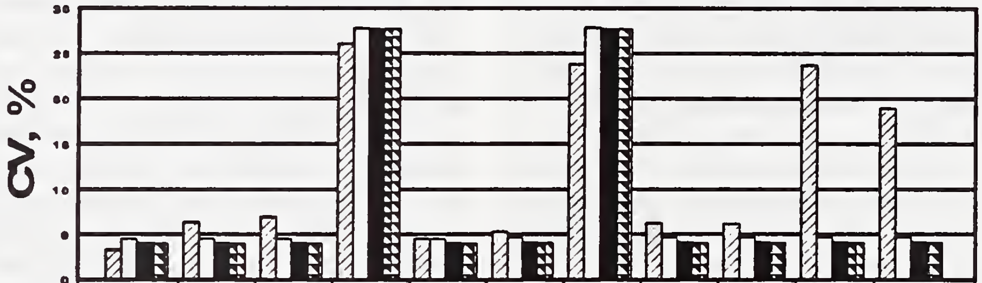
Results of Field Tests and Model Simulations WSFS, Agrifim In-Line Tube, 91m Tube Length



	PL2P0	PL4P0	PL7P0	PL11P0*	PL11P0	PL2P1	PL11P1*	PL11P1	PL7P?	PL11P2**	PL11P2
Field Test	97.0	95.87	94.66	90.30	96.4	95.92	89.92	94.92	95.87	83.66	90.67
EGL	96.31	96.31	96.31	85.87	96.31	96.33	86.00	96.33	96.23	96.23	96.33
REGL	96.66	96.66	96.66	86.86	96.66	96.61	86	96.61	96.61	96.61	96.61
SBS	96.74	96.74	96.74	86	96.74	96.7	86	96.7	96.7	96.7	96.7

* Emitter plugging included
** Unrepaired leaks included
P0: 4 drip tubes
P1 or P2: 3 drip tubes
Emitter Parameters: k-1.2341, x-0.5107, CV(M)-2.5%

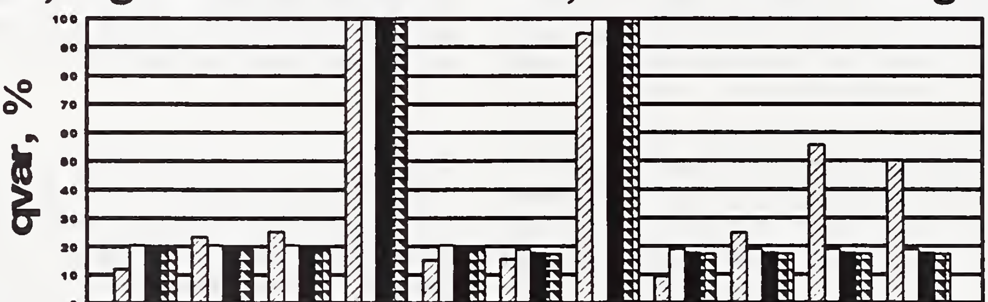
Results of Field Tests and Model Simulations WSFS, Agrifim In-Line Tube, 91m Tube Length



	PL2P0	PL4P0	PL7P0	PL11P0*	PL11P0	PL2P1	PL11P1*	PL11P1	PL2P2	PL11P2**	PL11P2
Field Test	3.3	6.38	6.92	26.1	4.47	5.27	23.70	6.17	6.11	23.74	18.82
EGL	4.47	4.47	4.47	27.84	4.47	4.9	27.86	4.9	4.9	4.9	4.9
REGL	4.05	4.05	4.05	27.73	4.05	4.16	27.70	4.16	4.16	4.16	4.16
SBS	3.87	3.87	3.97	27.73	3.87	4.05	27.76	4.05	4.05	4.05	4.05

* Emitter plugging included
** Unrepaired leaks included
P0: 4 drip tubes
P1 or P2: 3 drip tubes
Emitter Parameters: k-1.2341, x-0.5107, CV(M)-2.5%

Results of Field Tests and Model Simulations WSFS, Agrifim In-Line Tube, 91m Tube Length



	PL2P0	PL4P0	PL7P0	PL11P0*	PL11P0	PL2P1	PL11P1*	PL11P1	PL2P2	PL11P2**	PL11P2
Field Test	12.2	23.35	25.1	100	15.32	15.36	94.61	9.26	24.7	55.73	50.3
EGL	20.42	20.42	20.43	100	20.42	18.63	100	18.63	18.63	18.63	18.63
REGL	19.66	19.66	19.66	100	19.66	17.63	100	17.63	17.62	17.63	17.63
SBS	19.6	19.6	19.6	100	19.6	17.37	100	17.37	17.37	17.37	17.37

* Emitter plugging included
** Unrepaired leaks included
P0: 4 drip tubes
P1 or P2: 3 drip tubes
Emitter Parameters: k-1.2341, x-0.5107, CV(M)-2.5%

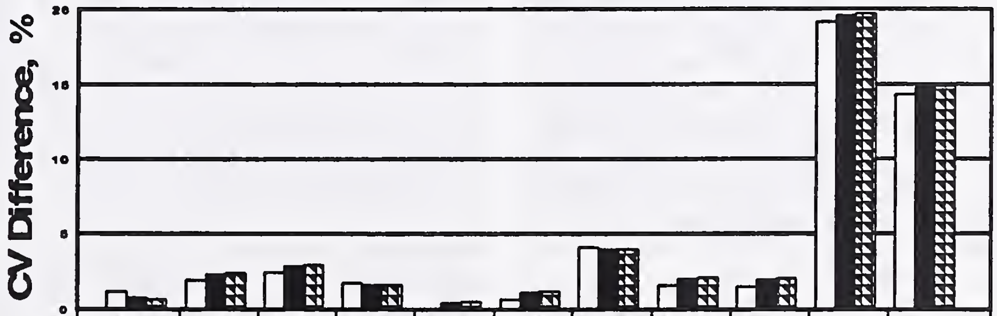
Figure 1.

Difference Between Tests and Simulations
WSFS, Agrifim In-Line Tube, 91m Tube Length

	PL2P0	PL4P0	PL7P0	PL11P0*	PL11P0	PL2P1	PL11P1*	PL11P1	PL2P2	PL11P2**	PL11P2
EGL	1.19	0.44	1.46	4.39	0.09	0.61	3.65	1.41	0.26	12.57	5.66
REGL	0.84	0.79	1.91	4.37	0.36	0.99	3.62	1.79	0.64	12.95	5.94
SBS	0.76	0.87	1.89	4.36	0.34	1.09	3.62	1.89	0.73	13.04	6.03

* Emitter plugging included
** Unrepaired leaks included
P0: 4 drip tubes
P1 or P2: 3 drip tubes
Emitter Parameters: k-1.2341, x-0.5107, CV(M)-2.5%

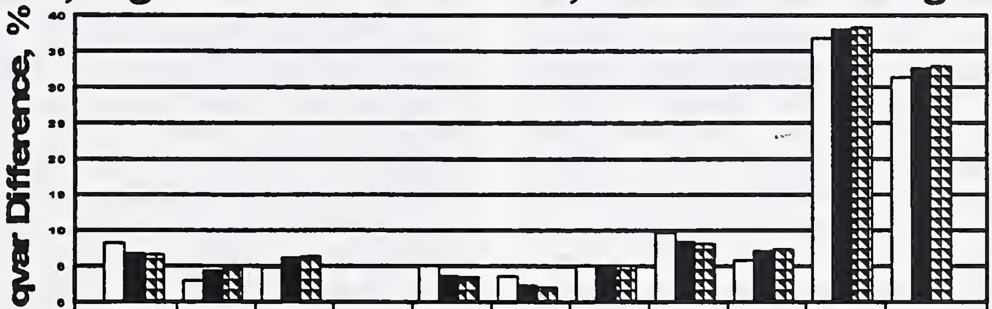
Difference Between Tests and Simulations
WSFS, Agrifim In-Line Tube, 91m Tube Length



	PL2P0	PL4P0	PL7P0	PL11P0*	PL11P0	PL2P1	PL11P1*	PL11P1	PL2P2	PL11P2**	PL11P2
EGL	1.17	1.91	2.46	1.74	0	0.67	4.1	1.57	1.51	19.14	14.32
REGL	0.78	3.33	3.07	1.93	0.42	1.12	4	2.03	1.96	19.89	14.77
SBS	0.67	2.41	2.96	1.62	0.6	1.22	4	2.12	2.06	19.89	14.97

* Emitter plugging included
** Unrepaired leaks included
P0: 4 drip tubes
P1 or P2: 3 drip tubes
Emitter Parameters: k-1.2341, x-0.5107, CV(M)-2.5%

Difference Between Tests and Simulations
WSFS, Agrifim In-Line Tube, 91m Tube Length



	PL2P0	PL4P0	PL7P0	PL11P0*	PL11P0	PL2P1	PL11P1*	PL11P1	PL2P2	PL11P2**	PL11P2
EGL	8.22	2.93	4.99	5	5.1	3.67	5.59	9.66	5.77	36.9	31.37
REGL	6.79	4.39	6.11	5	3.97	3.27	5.59	8.36	7.67	38.1	33.07
SBS	6.5	4.66	6.3	5	3.49	2.61	5.59	8.09	7.33	38.36	33.93

* Emitter plugging included
** Unrepaired leaks included
P0: 4 drip tubes
P1 or P2: 3 drip tubes
Emitter Parameters: k-1.2341, x-0.5107, CV(M)-2.5%

Figure 2.

NITROGEN MANAGEMENT OF COTTON UNDER SUBSURFACE DRIP IRRIGATION: IDENTIFICATION OF CRITICAL N LEVELS

R.B. Hutmacher, C.J. Phene, T.A. Kerby, S.S. Vail,
C.A. Hawk, M.S. Peters, M. Keeley, A. Bravo, T. Pflaum

OBJECTIVES: This subsurface drip irrigation experiment is part of a series of three to five year cooperative projects with the goal of identification of specific relationships between nitrogen fertilizer applications and soil nitrogen status, measured plant nutrient uptake, growth rates, yield, and various physiological responses (at the leaf and whole-plant level) of cotton to N availability. The subsurface drip system is being used in a portion of this experiment to provide a means to deliver precise amounts of N over time and identify plant responses to different severities and timing of nitrogen deficits.

PROCEDURES: *Irrigation System.* 1993 will be the first year of a three- to five-year study. The cotton variety used in the drip study will be "Maxxa". The drip system consists of drip laterals spaced 1.52 m apart, centered on every other furrow, and 45 cm below the average soil surface. Drip emitters are 1.02 m apart on the drip laterals and are turbulent-flow, in-line style with a nominal flow of 2 L h^{-1} at 18 to 20 psi operating pressure. Each plot consists of 12 rows of plants, spaced 0.76 m apart and 9.3 m in length.

N Fertilizer Treatments. There will be nine fertilizer treatments which will include combinations of patterns of nitrogen application (linear versus growth-stage and uptake rate-dependent), total amount of nitrogen applied (targets of 60, 120, 180 kg N ha^{-1}), and amount of pre-plant fertilizer applied (0 versus 50 kg N ha^{-1}). All fertilizer treatments are replicated four times. Phosphoric acid and potassium thiosulfate will supply phosphorus and potassium requirements for the crop, respectively, and will be injected using a proportional fertilizer injector. Potassium thiosulfate applications will be made once per week and will be separate in time from phosphoric acid and calcium-ammonium nitrate applications (which are continuous during all other irrigations) in order to avoid potential interactions between nutrient sources. Differential N application treatments will require use of venturi-type injectors and secondary pressure regulators to assure proper flow and application rates across treatments.

Soil and Plant Sampling. All fertilizer treatments will receive the same amount of water. Initial soil samples will be collected to a depth of 3 m to determine initial soil N fractions. Additional soil samples will be collected at harvest to identify end-of-season N status.

Petiole samples from the most recent fully-expanded leaves will be collected weekly and analyzed for NO3-N, PO4-P, and K. Above-ground plant samples will be collected twice during the season to identify above-ground nutrient uptake based on average tissue concentrations and dry matter sampling of component plant parts. Main stem and symodial leaves at different positions within the canopy will be sampled at intervals through the season and analyzed for gas exchange rates, total-N, chlorophyll levels, and incident radiation. Leaf sample cores will be sampled at first bloom, peak bloom and during boll development by University of CA cooperators to identify changes in soluble protein levels and activity of specific enzymes.

Plant water status will be monitored using infrared thermometry and CWSI methods. Plant growth and development will be monitored as plant height, node counts, nodes above white bloom. Plant mapping will be done in conjunction with University of CA cooperators on the project. Yields will be determined on two rows per plot using a modified commercial-type spindle picker.

FUTURE PLANS: The project plans are to proceed as described above during the 1993 season, and continue on larger plots during the following season. Measurements will likely be modified based on the relative success in identifying crop responses to adequate versus deficient N. The long-term goal is to identify growth-stage-specific levels of nitrogen and their relationships to physiological functions, growth and yield-limitations. Other related projects will be initiated in 1993 at other sites under furrow irrigation.

SUBSURFACE DRIP IRRIGATION OF ACALA AND PIMA COTTON: PLANT WATER RELATIONS

R.B. Hutmacher, C.J. Phene, K.R. Davis, T. Kerby, M. Peters, S.S. Vail, D. Ballard, N. Hudson, A. Bravo, J. Misaki, D. Clark, M. Keeley

OBJECTIVES: The overall objectives of this project were to evaluate the responses of three types of cotton (Acala "GC510" and "Columnar" and Pima "S6") grown under subsurface drip irrigation and a narrow-row (76 cm row spacing) production system. Crop water requirements, use of stored soil water, root distribution and density, and specific crop growth, plant water status, plant nutrient status and uptake, and gas exchange responses to irrigation ranging from mild to moderate deficit irrigation in a clay loam soil will be determined in this study.

PROCEDURES: 1992 was the second year of this three-year cotton study in a Panoche clay loam soil at the University of California West Side Research and Extension Center. Row spacing was 76 cm and the drip irrigation laterals were shanked in about 45 cm deep in alternate furrows, centered in the furrows. Details of the drip irrigation system, its operation and application amounts, and methods of determining grass reference evapotranspiration (ET_o) and crop coefficients are given in this volume in the report "Subsurface drip irrigation of Acala and Pima cotton: Operational procedures". Six subsurface drip irrigation treatments were evaluated, with the treatments representing six different combinations of percentages of crop ET applied during specific portions of the growing season, as described in the "Operational Procedures" report on this project.

The responses of three types of cotton were evaluated within each of the six irrigation treatments: (1) a commercial narrow-row cotton (GC-510); (2) a columnar-type cotton out of the University of California cotton program; and (3) a "Pima" type (Pima S6). All three types of cotton were grown at the same planting density and cultural conditions were identical across the three cotton types. Each individual plot was split into 5 rows which were sprayed once per season with the growth regulator "PIX" (Mepiquat chloride), and 5 rows which were not sprayed ("No Pix" plots), with the PIX applied on July 9 at a rate of 0.5 pints per acre.

Early- to mid-afternoon leaf water potentials (LWP) were determined on selected treatments (irrigation and PIX treatments) in all three cotton types (Pima, GC510, Columnar) using a Schollander-type pressure chamber. Three subsamples were evaluated in each of three field replications for each treatment. Fully-illuminated, recently-mature leaves from the fourth or fifth most recent main stem node position were placed in a plastic bag while still on the plant, excised, and stored temporarily in humid, sealed plastic containers, and leaf water potentials were determined within 10 to 15 minutes of collection. Infrared thermometer and psychrometer data for determination of the crop water stress index (CWSI) was also collected in select plots, but will not be discussed here.

RESULTS: As in the 1991 season, within any individual irrigation treatment, few significant differences in LWP existed between the Columnar and GC510 types. In the early season (prior to day 180), LWP in the T1 treatment (which received the most applied water) averaged -1.2 to -1.5 MPa in these varieties, declining to about -1.7 to -1.8 MPa in the late season (Fig. 1). In contrast, the LWP in the treatment receiving the least applied water (T6) declined to -2.0 MPa by day 200 and to less than -2.2 MPa by day 215 (Fig. 2). LWP levels in all three varieties and all irrigation treatments were 0.15 to 0.30 MPa lower than during comparable periods in 1991, perhaps reflecting the lower initial stored soil water levels in 1992.

Across all irrigation treatments (T1, T6 shown in Figs. 1, 2 respectively), the Pima type cotton exhibited 0.1 to 0.2 MPa lower LWP than the Acala types. Similar differences between Acala and Pima types were noted during the 1991 season. A less extensive root system or differences in plant hydraulic resistance associated with some other plant characteristic may explain this difference. LWP of other irrigation treatments were intermediate between T1 and T6 (Fig. 2 for GC510 only).

FUTURE PLANS: This experiment will be repeated in its entirety during the 1993 growing season. Similar measurements will be made during the third year of the study. These results will provide crop-specific plant water status data to describe specific indexes of plant water deficits that can be associated with favorable or unfavorable yield responses.

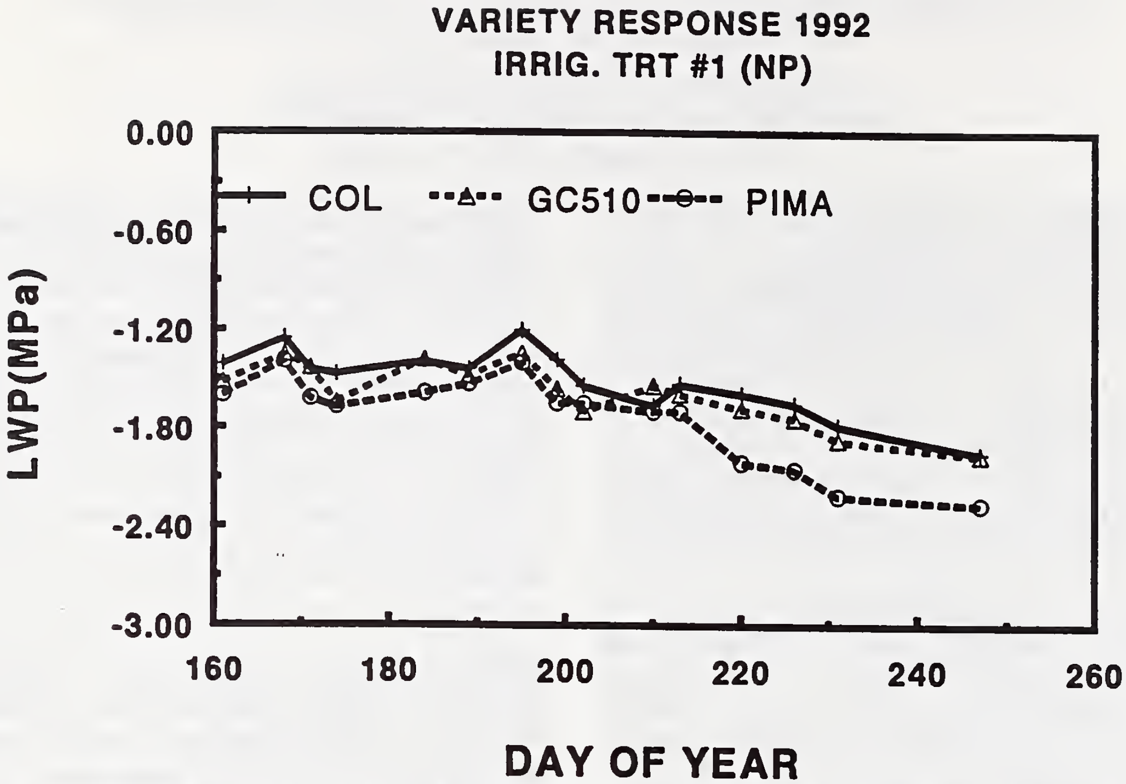


Figure 1. Mid-afternoon leaf water potential (LWP) of fully-illuminated, recent fully-expanded leaves of Columnar, Pima and GC510 types of cotton as a function of day of year in irrigation treatment T1. All data shown is for "no pix" (NP) subplots.

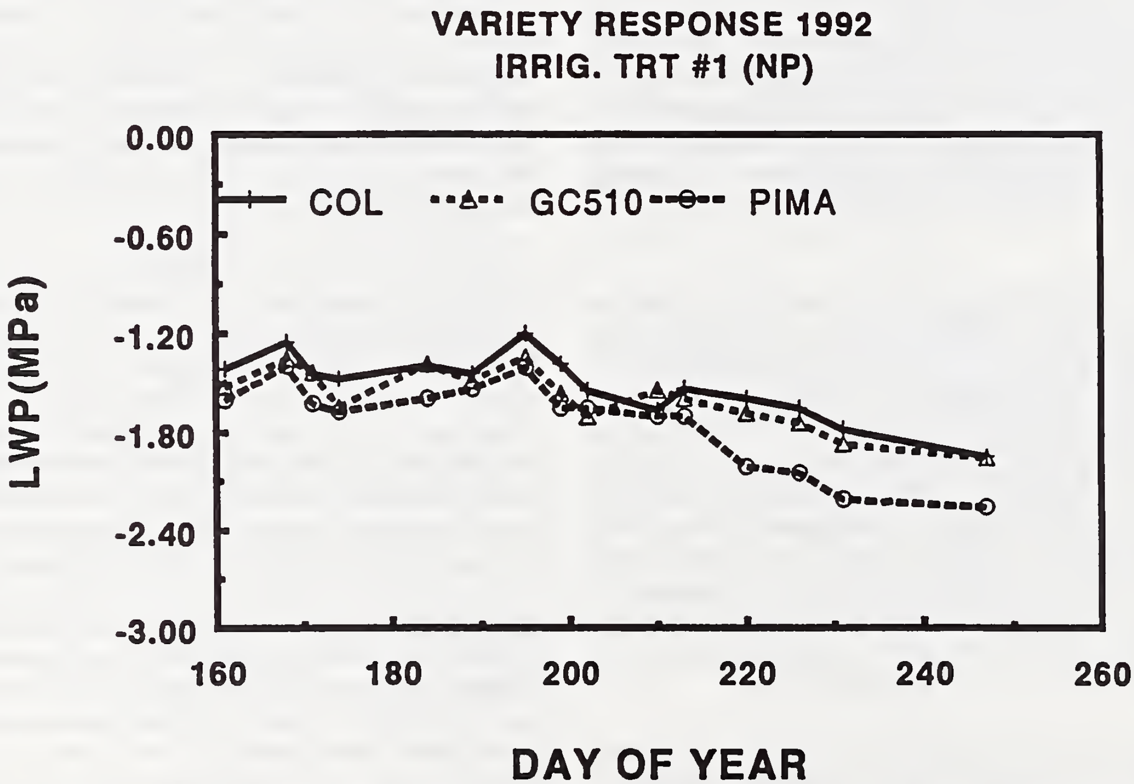


Figure 2. Mid-afternoon leaf water potential (LWP) of fully-illuminated, recent fully-expanded leaves of GC510 cotton as a function of day of year in irrigation treatments T1, T3, T4, T6. All data shown is for "no pix" subplots.

SUBSURFACE DRIP IRRIGATION OF ACALA AND PIMA COTTON: PETIOLE N, P, AND K LEVELS DURING SEASON

R.B. Hutmacher, C.J. Phene, K.R. Davis, T. Kerby, M. Peters, S.S. Vail, T. Pflaum, D. Ballard, N. Hudson, C. Ament, A. Bravo, D. Clark, M. Keeley, A. Nevarez, E. Ehn, C. Horder

OBJECTIVES: The overall objectives of this project are to evaluate the responses of three types of cotton grown under subsurface drip irrigation and a narrow-row (76 cm row spacing) production system. Crop water requirements, use of stored soil water, root distribution and density, and specific crop growth, plant water status, and gas exchange responses to irrigation ranging from mild to moderate deficit irrigation in a clay loam soil will be determined in this study.

PROCEDURES: In the second year of a three year study, cotton was grown during 1992 in a Panoche clay loam soil at the University of California West Side Research and Extension Center. Row spacing was 76 cm and the drip irrigation laterals were shanked in about 45 cm deep in alternate furrows, centered in the furrows. Details of the drip irrigation system, its operation and application amounts, and methods of determining grass reference evapotranspiration (ET_o) and crop coefficients are given in this volume in the report "Subsurface drip irrigation of Acala and Pima cotton: Operational procedures". Six subsurface drip irrigation treatments were evaluated, with the treatments representing six different combinations of percentages of crop ET applied during specific portions of the growing season, as described in the "Operational Procedures" report on this project.

Nutrient application rates and periods of application are described in "Subsurface drip irrigation of Acala and Pima cotton: Operational Procedures" elsewhere in this report. N, P, and K were supplied through injection of calcium-ammonium nitrate and potassium nitrate, phosphoric acid, and potassium nitrate, respectively. Phosphoric acid was applied throughout the irrigation season as a continuous injection resulting in a concentration of 15 mg/kg in the irrigation water. Calcium ammonium nitrate was applied during about the first three-quarters of the irrigation season and potassium nitrate during the last portion of the growing season. Calcium nitrate and potassium nitrate applications did not overlap in time. The rationale for these nutrient changes was to apply a higher N-content material (calcium ammonium nitrate) during the peak N demand period (early to mid-season) and apply a lower N-content material and K during the high K uptake period (mid- to late-season).

A minimum of twenty petioles were collected from each of three field replicate plots of each treatment evaluated. Samples were collected from the fourth or fifth most recent node prior to 0930 hours PDT at 7 to 10 day intervals throughout the season, dried at 50 to 55 C, and analyzed for NO_3-N, PO_4-P, and K.

RESULTS: Even though water applications across treatments differed significantly (see "Subsurface drip irrigation of cotton: Applied water, soil water use, evapotranspiration"; this report), nutrient applications were uniform across all irrigation levels. There were few significant interactions between irrigation treatments and petiole nutrient status (data not shown).

Across all three types of cotton, petiole NO_3-N levels were generally slightly below or within University of California recommended NO_3-N levels for cotton during the early to mid-season (prior to day 190) under both low water stress (treatment T1) and higher water stress (treatments T4, T6) conditions (Fig. 1). During mid-to late-season, petiole NO_3-N levels of the Acala types were closer to the low end of recommended levels. Petiole NO_3-N levels of Pima (Fig. 1b) were usually significantly lower than in the Acala types, particularly in the early- to mid-season period (days 160 to 210). Since lint yields were high in all plots despite what generally could be regarded as barely sufficient petiole nitrogen levels during some growth stages, this data may indicate a need to reevaluate guidelines for petiole nutrient levels for drip irrigated cotton. Although not all soil nutrient data has been fully analyzed, available data indicates that soil N levels at planting were quite low, suggesting little carryover of N from previous crops.

Petiole P and K levels were at or in excess of "sufficient" levels identified by the University of California in prior studies (Figs. 1c through 1f). No consistent differences in petiole P or K status were observed between irrigation treatments or across different types of cotton. This is in contrast to data from 1991, when Pima K levels were consistently lower than those observed in the Acala types.

FUTURE PLANS: This experiment will be repeated in its entirety during the 1993 growing season. In future experiments, the influence of leaf position and leaf age on cotton N levels will be measured directly through nitrate and Kjeldahl-N determinations, and indirectly through measurements of seasonal and age-related changes in leaf chlorophyll fluorescence. The lower petiole nutrient levels observed in Pima relative to the Acala types will be investigated in future studies to determine the consistency of this response across years.

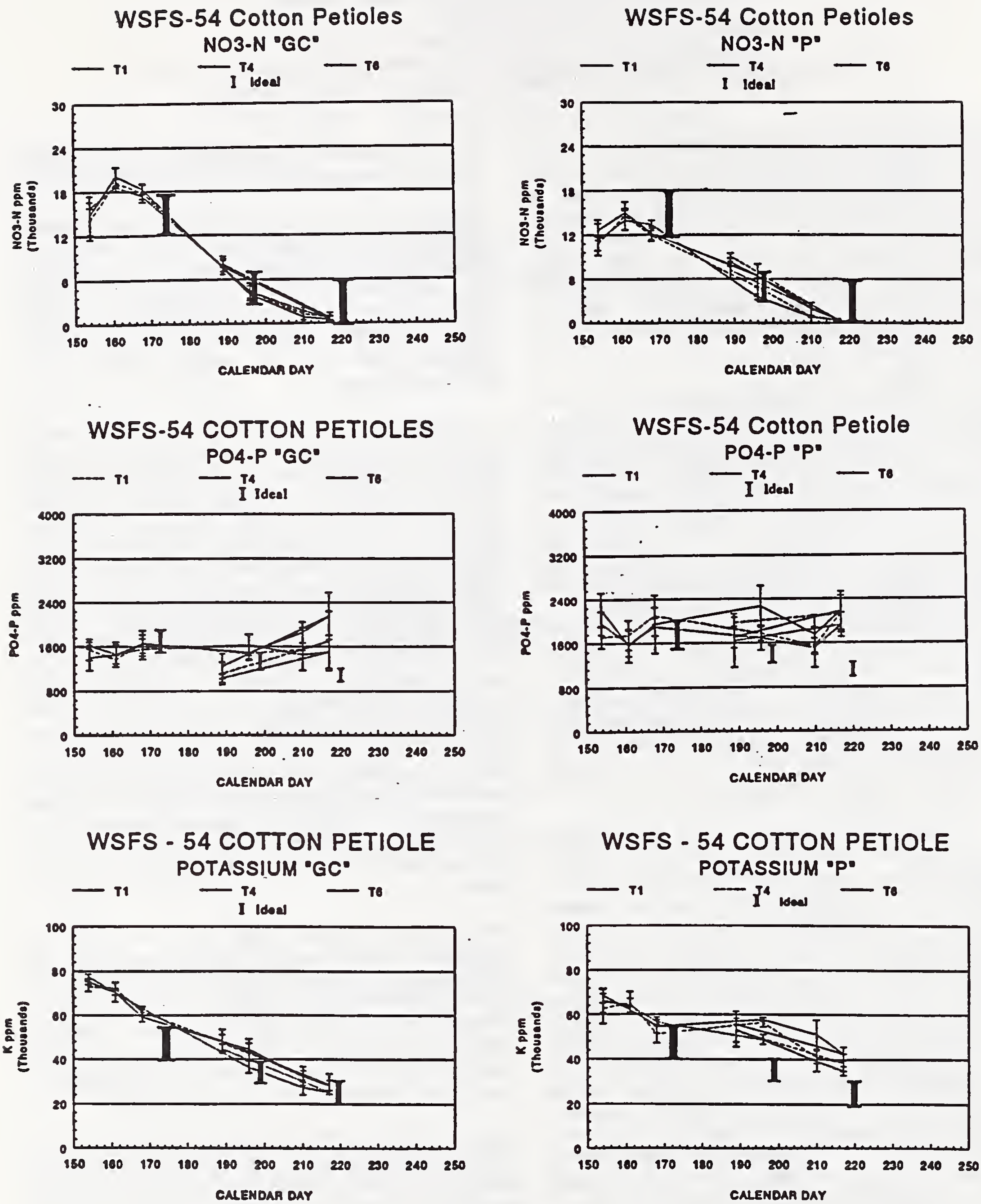


Figure 1. Petiole levels of nitrate, phosphate, and potassium as a function of day of year for columnar (C), GC510 (GC), and Pima (P) types of drip irrigated cotton at the West Side Field Station in 1992 for irrigation treatments T1, T4, T6. Shown are: petiole nitrate for GC510 (1a) and Pima cotton (1b); petiole phosphorus for GC510 (1c) and Pima cotton (1d); and petiole potassium for GC510 (1e) and Pima cotton (1f). The dark vertical bars indicate University of CA recommended ranges for petiole nutrient concentrations during specific growth stages.

SUBSURFACE DRIP IRRIGATION OF ACALA AND PIMA COTTON: SEED COTTON AND LINT YIELDS

R.B. Hutmacher, C.J. Phene, K.R. Davis, T. Kerby, M. Peters, S.S. Vail, R. Mead, D. Ballard, N. Hudson, A.Bravo, T. Pflaum, D. Clark, M. Keeley

OBJECTIVES: The overall objectives of this project were to evaluate the responses of three types of cotton grown under subsurface drip irrigation and a narrow-row (76 cm row spacing) production system. Crop water requirements, use of stored soil water, root distribution and density, and specific crop growth, plant water status, and gas exchange responses to irrigation ranging from mild to moderate deficit irrigation in a clay loam soil will be determined in this study.

PROCEDURES: Cotton was grown during 1992 in a Panoche clay loam soil at the University of California West Side Research and Extension Center. Row spacing was 76 cm and the drip irrigation laterals were shanked in about 45 cm deep in alternate furrows, centered in the furrows. Details of the drip irrigation system, its operation and application amounts, and methods of determining grass reference evapotranspiration (ET_o) and crop coefficients are given in this volume in the report "Subsurface drip irrigation of Acala and Pima cotton: Operational procedures". Six subsurface drip irrigation treatments were evaluated, with the treatments representing six different combinations of percentages of crop ET applied during specific portions of the growing season, as described in the "Operational Procedures" report on this project.

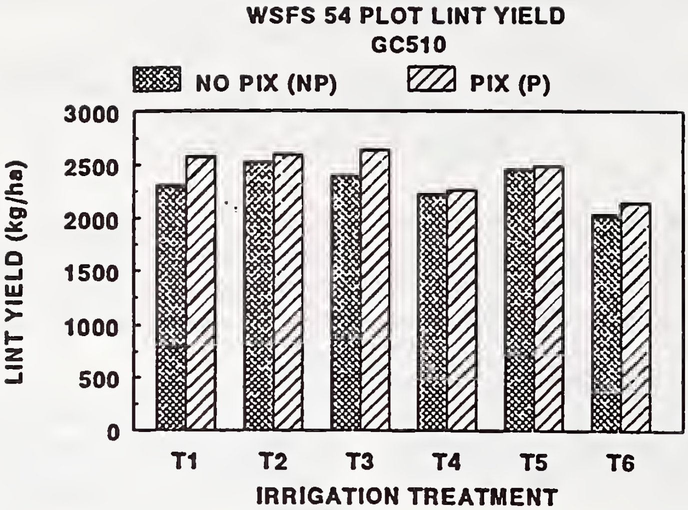
The responses of three types of cotton were evaluated within each of the six irrigation treatments: (1) a commercial narrow-row cotton (GC-510); (2) a columnar-type cotton out of the University of California cotton program; and (3) a "Pima" type (Pima S6). All three types of cotton were grown at the same planting density and cultural conditions were identical across the three cotton types. Each individual plot was split into 5 rows which were sprayed once per season with the growth regulator "PIX" (Mepiquat chloride), and 5 rows which were not sprayed ("No Pix" plots), with the PIX applied on July 9 at a rate of 0.5 pints per acre.

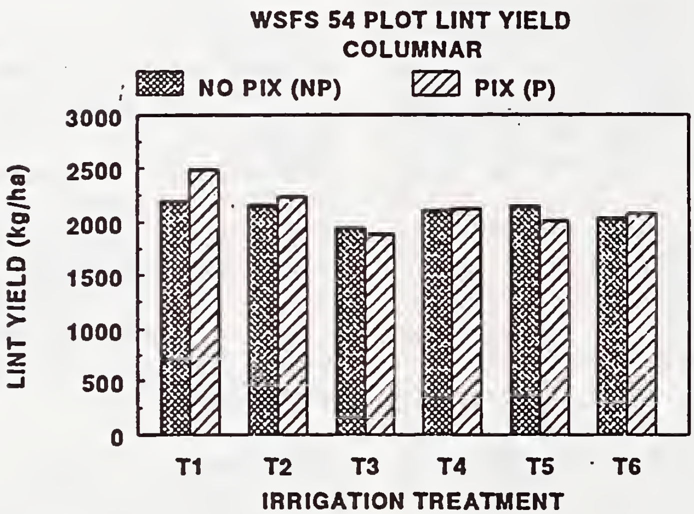
Cotton lint yields were measured on 25 to 30 m sections of planted rows in each plot using a modified commercial spindle-picker harvester. Gin turnout percentages were determined at the UC/USDA cotton lab in Shafter, CA.

RESULTS: In 1991 there were no consistent yield responses to PIX treatments within any type of cotton. In 1992, there was an average 2 to 5% yield increase with PIX in the higher water application treatments with both Acala varieties (Fig. 1). Plants were more vigorous and taller in 1992 than in 1991. In contrast, there was a trend toward slightly lower (2 to 6%) yields with PIX applications in the Pima variety. The following discussion of responses to irrigation treatments generally is applicable to the average irrigation treatments response across PIX treatments.

Considering the relatively broad range of applied water across the six irrigation treatments, lint yields within each variety were all within a relatively narrow range. Pima lint yields ranged from 2009 to 2161 kg ha^{-1} with an average of 2103 kg ha^{-1}, GC510 ranged from 2091 to 2562 kg ha^{-1} with an average of 2388 kg ha^{-1}, Columnar ranged from 1915 to 2339 kg ha^{-1} with an average of 2116 kg ha^{-1} (Fig 1).

FUTURE PLANS: This experiment will be repeated in its entirety during the 1993 growing season.





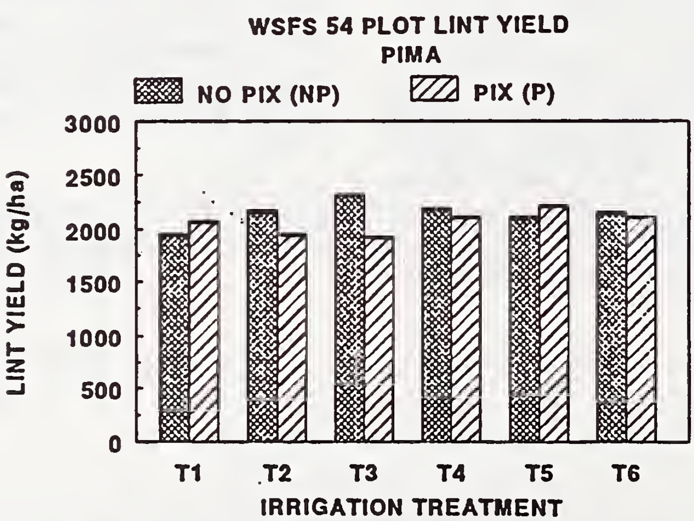


Figure 1. Cotton lint yields of "np" (plots not receiving a foliar PIX application) and "p" (plots receiving foliar PIX application) subsurface drip irrigated plots as a function of irrigation treatments (Treatment 1 through 6) and cotton type (Columnar – Figure 1a; GC510 – Figure 1b; Pima – Figure 1c) at the West Side Research and Extension Center in 1992.

SUBSURFACE DRIP IRRIGATION OF ACALA AND PIMA COTTON: EFFECTS OF LEAF POSITION AND AGE ON LEAF CONDUCTANCE AND PHOTOSYNTHETIC RATES

R.B. Hutmacher, C.J. Phene, K.R. Davis, T. Kerby, M. Peters, S.S. Vail, D. Ballard, N. Hudson, D. Clark, M. Keeley, A. Bravo

OBJECTIVES: The overall objectives of this project were to evaluate the responses of three types of cotton grown under subsurface drip irrigation and a narrow-row (76 cm row spacing) production system. Crop water requirements, use of stored soil water, root distribution and density, and specific crop growth, plant water status, and gas exchange responses to irrigation ranging from mild to moderate deficit irrigation in a clay loam soil will be determined in this study.

PROCEDURES: Cotton was grown during 1992 in a Panoche clay loam soil at the University of California West Side Research and Extension Center. Row spacing was 76 cm and the drip irrigation laterals were shanked in about 45 cm deep in alternate furrows, centered in the furrows. Details of the drip irrigation system, its operation and application amounts, and methods of determining grass reference evapotranspiration (ET_o) and crop coefficients are given in this volume in the report "Subsurface drip irrigation of Acala and Pima cotton: Operational procedures". Six subsurface drip irrigation treatments were evaluated, with the treatments representing six different combinations of percentages of crop ET applied during specific portions of the growing season, as described in the "Operational Procedures" report on this project.

The gas exchange responses of three types of cotton were evaluated within two irrigation treatments, T1 and T6. These treatments represent those with the most (T1) and least (T6) applied water across the treatments. In 1992, all three types of cotton were grown at the same planting density and cultural conditions were identical across the three cotton types.

Single leaf photosynthetic rates were determined using a flow-through chamber system with an ADC gas analyzer. A 4.2 cm^2 area was monitored on each sample leaf. Data was collected on GC510, Pima and Columnar types of cotton, however, emphasis was on GC510, a variety widely-grown under narrow-row (76 cm row width) conditions. Only data collected for GC510 will be reported here. Measurements were made on leaves located on the 3rd, 5th, 8th, and 11th most-recent main stem nodes, and on 1st and 2nd position (if present) sympodial leaves arising from the 8th through 11th most-recent nodes. Leaf conductance and transpiration data collected using the leaf chamber were compared with selective measurements made using a steady-state diffusion porometer. In the upper canopy nodes, leaves were fully-illuminated, while lower canopy leaves were monitored under ambient light levels (some measurements specifically made under shaded conditions and some under fully-illuminated conditions). Data on leaves was recorded by node position and average leaf initiation date in order to accurately identify leaf age as well as position.

RESULTS: *Influence of position on the plant.* Average single leaf photosynthetic rates across all three cotton types were consistently highest in leaves from the 5th most recent node, and over all sample dates, averaged 21%, 8%, and 27% lower in fully-illuminated 3rd, 8th, and 11th most-recent node leaves, respectively. As in data collected in 1991, leaf conductance values were not tightly linked with photosynthetic rates, with the highest conductance measured in leaves from the 3rd or 5th most recent node. Similarly, lower photosynthetic rates in the 8th most recent node leaves were not associated with reductions in leaf conductance. At high irradiance levels, differences in photosynthetic rates in different leaf positions were not tightly coupled with changes in conductance. Lower in the canopy, where photosynthetic photon flux densities of less than 350 to 550 µmoles photons m^{-2} s^{-1} were common, reduced photosynthetic rates were positively correlated with reductions in conductance.

During the early boll-filling period (mid- to late-July), leaves from the 11th through 13th most-recent node and sympodial leaves from any position typically were under low photosynthetic photon flux density (PPFD) levels (less than 350 µmoles photons m^{-2} s^{-1}), resulting in net photosynthetic rates ranging from near 0 to about 32% (5 to 6 µmol CO_2 m^{-2} s^{-1}) of the levels in main stem leaves from the 5th most-recent node.

As in 1991, a major problem in sampling the sympodial and lower canopy leaves for photosynthetic rates is the variability in light levels (transient high PPFD values, followed by major periods of low PPFD) in typical fruiting branches. In mid-July, when sympodial leaves from intermediate-canopy positions (fruiting branch on 10th, 11th or 12th

most-recent node) were found which were sunlit (greater than 800 µmol photons m^{-2} s^{-1}) for a minimum of 10 to 15 minutes, average net photosynthesis was 18 µmol CO_2 m^{-2} s^{-1}. During low sunlight conditions, however, much lower photosynthetic rates prevailed, resulting in relatively low photosynthetic productivity for sympodial leaves, particularly those at lower positions in the canopy. In all of these cases, the ratio of leaf conductance to photosynthesis was lower under low light conditions and with older leaves, indicating that stomata did not represent the major restriction to photosynthetic rates.

Influence of leaf age and position. Data collected during rapid leaf area development (June through mid-July) indicated that at ages 26, 33, 43, and 50 days after leaf initiation, sunlit main stem leaves had average photosynthetic rates which were 106%, 88%, 74%, and 54% of the rates measured in 16 to 21 day-old main stem leaves (data not shown). Initiation of new main stem leaves essentially terminated during the second week of August in most irrigation treatments of the GC510 variety. From this point on, most of the illuminated leaves were aging at a time when the developing bolls had a high carbohydrate demand. Across all leaf positions, leaf photosynthetic rates showed an average 26% decline during a 20 day period in early to late August, with an additional 19% reduction during the next 11 days. The decline was more rapid in the severe water deficit treatment (T6).

Efforts will be made to evaluate the more limited data from Pima and Columnar types for significant differences from GC510 observations.

FUTURE PLANS: Further analysis of existing data is underway to determine the influence of types of cotton (GC510 vs. Columnar, Pima) on the observed responses. In future experiments, the influence of leaf position and leaf age on cotton N levels will be measured directly through nitrate and Kjeldahl-N determinations, and indirectly through measurements of seasonal and age-related changes in leaf chlorophyll fluorescence. This information may provide additional guidelines for interpreting gas exchange measurements.

SUBSURFACE DRIP IRRIGATION OF ACALA AND PIMA COTTON: ROOT LENGTH DENSITY AND DISTRIBUTION AS AFFECTED BY GROWTH STAGE, IRRIGATION TREATMENT, DEPTH, AND DISTANCE FROM EMITTERS

C.J. Phene, R.B. Hutmacher, K.R. Davis, T. Kerby, J. Misaki, A. Nevarez, C. Ament, R. Mead, D. Ballard, N. Hudson, C. Hawk, S.S. Vail, D. Clark, M. Keeley

OBJECTIVES: The overall objectives of this project were to evaluate the responses of three types of cotton grown under subsurface drip irrigation and a narrow-row (76 cm row spacing) production system. Crop water requirements, use of stored soil water, root distribution and density, and specific crop growth, plant water status, and gas exchange responses to irrigation ranging from mild to moderate deficit irrigation in a clay loam soil will be determined in this study.

PROCEDURES: Cotton was grown during 1992 in a Panoche clay loam soil at the University of California West Side Field Station. Row spacing was 76 cm and the drip irrigation laterals were shanked in about 45 cm deep in alternate furrows, centered in the furrows. Details of the drip irrigation system, its operation and application amounts, and methods of determining grass reference evapotranspiration (ET_o) and crop coefficients are given in this volume in the report "Subsurface drip irrigation of Acala and Pima cotton: Operational procedures". Six subsurface drip irrigation treatments were evaluated, with the treatments representing six different combinations of percentages of crop ET applied during specific portions of the growing season, as described in the "Operational Procedures" report on this project.

Soil samples for determination of root length density and weight were collected in plots from variety GC510 in three field replications each of treatments T1, T4, and T6. Samples were collected three times during the growing season: (1) during square development in June; (2) after peak flowering in late July; and (3) during boll maturation close to irrigation cutoff in late August to early September, 1992. A total of six sample locations were identified in each plot, with three of the sample sites situated along a line perpendicular to the drip lateral, starting adjacent to an emitter (site A1); the next sample location in line with the plant row (site A2), and the next location in the dry (no drip line) furrow (site A3). The other three sample locations (designated as M1, M2, M3) correspond to locations A1, A2, A3 in terms of position relative to the drip lateral, however, the M1 position is midway on the lateral between emitters (about 45 cm from the emitter).

In each of these six locations per plot, soil samples were collected in 15 cm increments to a depth of 270 cm using a Giddings sample tube. Soil samples were collected and stored under refrigeration until processed. Subsamples were collected for determination of soil water content, and bulk soil wet weights and dry weights were determined. Processing the samples for determination of root length density involved physical washing of the soil/root samples using dilute acetic acid to aid in floating and separation of organic matter. Roots were separated from other organic matter by hand, stained with a dilute methyl violet, and root length measured using a calibrated video area meter. Root length density was calculated using measured root lengths and soil dry weights.

Root samples collected using the above procedure were dried at 55 C for 24–48 hours, then weighed and expressed as root dry weight per unit weight of soil.

RESULTS: Due to the extensive number of samples collected, it was decided to concentrate first on analysis of samples from hole locations A1, A2, A3, and M1. Samples from hole locations M2 and M3 were set aside for running later if time and labor permitted.

The basic difference between the 1991 and 1992 sampling schemes was that the 1991 data represented end-of-season roots remaining after irrigation cutoff. In 1992, samples were made during periods when active root growth should have been underway, with other sample dates to follow changes in root system development as the crop developed a full above-ground canopy and bolls matured.

General Effects of Sampling Location Within Beds: In sampling done in June and July, samples evaluated to date indicated root length density (RLD) was generally highest at the 45 cm and 60 cm depths, with the lowest at the surface sample (0 to 15 cm depth) and below 2 m depth. In both location A1 and M1 (closest to the emitter) in most plots, RLD at the 45 to 75 cm depths was significantly higher than in corresponding A2, A3, M2, M3 sampling locations in June and some July sampling dates. The

analysis of July and September samplings was not complete when this report was submitted. At other depths, RLD's were generally similar across the sample locations, with values ranging from 0.2 to 0.45 cm root g^{-1} soil even at 2 m depth.

Effects of Irrigation Treatments: Soil profile water contents in the upper 1 m of the profile were quite high at the beginning of the 1992 growing season, but were much lower in the 1.25 to 2.5 m depths than in the early season of 1991. This undoubtedly had an impact on rooting patterns of the more severe deficit irrigation treatments, but data to evaluate this theory were not summarized at the time of this report. Soil water content will be closely monitored in future studies to relate measured RLD to soil water content. Root dry weights were positively correlated with calculated root length density, but r^2 values for linear regressions between them were generally less than 0.7 and were not significantly correlated at two of the six sample locations (averaged across all plots and treatments).

FUTURE PLANS: This experiment will be repeated in its entirety during the 1993 growing seasons, but the root sampling efforts will not be repeated except to a limited degree in 1993. Samples will be collected prior to planting in 1993 and analyzed for baseline RLD and root dry weights in order to determine the sensitivity of our root measurement methods to carryover of roots from one measurement period to the next. Data should be summarized and reports and a manuscript prepared during the coming year which will summarize both the 1991 end-of-season data as well as the growth stage dependent data from 1992.

SALINE AND NONSALINE MICRO-IRRIGATION OF ALMONDS: BORON UPTAKE AND SALINITY INTERACTIONS

R.B. Hutmacher, P. H. Brown, H.I. Nightingale, C.J. Phene, F.Dale, S.S. Vail, H. Hu, D.E. Rolston, D. Peters, J.W. Biggar, A. Bravo

OBJECTIVES: (1) To determine the potential for plant accumulation of boron or other potentially toxic constituents and injury under long-term use of saline irrigation water in drip irrigated almonds.

PROCEDURES: *Experimental Design*: Trees were grown in a Panoche Clay loam soil at the West Side Field Station of the University of California in a 6.1 m by 6.1 m square pattern which was planted in 1980. There were two primary experiments underway in the orchard during the past four seasons. The Butte cultivar was grown under 12 treatment combinations in 7 blocks with 7 trees per block. This cultivar was the primary cultivar evaluated for physiological responses to water application rates and water quality. One part of the experiment was an evaluation of crop response to a range of applied water (using five water application levels of nonsaline water (0.5 dS m^{-1}), described as fractions of ET (0.6, 0.8, 1.0, 1.2, 1.4 times estimated crop evapotranspiration (ET_c)). The other part of the experiment allowed comparison of tree responses to saline versus nonsaline irrigation. These five water application rates were also operated using saline (1.7 dS m^{-1}) water to evaluate responses to long-term use of saline irrigation water containing boron, chloride, and sodium in potentially problematic amounts. The Ruby cultivar was also evaluated at five irrigation rates using nonsaline water and one irrigation rate using saline water in order to compare cultivar differences in salt sensitivity and boron, sodium, and chloride accumulation in various tissues.

Most trees were irrigated using a line source trickle system with one lateral per row of trees. There were 6 emitters per tree with a nominal output of 2 L h^{-1} $emitter^{-1}$. Three emitters were located on either side of each tree, with the closest emitters 0.5 m from the tree and the second and third on each side 1.25 and 2.0 m from the tree, respectively. One treatment (the 1.0 times ET_c treatment) within each water quality was irrigated using two microsprays per tree, with each microspray having a wetted radius of approximately 2 m and a nominal output of 20 to 25 L h-1. The microspray treatments were used to evaluate tree responses to differences in water distribution and depth (in microspray versus line source drip).

The portion of the experiment described here has two basic parts: (1) a continuing sampling of plant tissue which was initiated in 1984 to monitor long-term changes in plant nutrient status and potential plant toxicity problems in foliar, woody, and fruit tissues; and (2) a cooperative study with Dr. P. Brown of the UC Davis Pomology Department in which tissue boron accumulation and distribution within the plant were being investigated during the 1989 through 1992 seasons. Part of this study was funded through the Salinity/Drainage Task Fsorce administered through the University of California. The UC Davis part of the investigation includes application and monitoring of the isotope ^{10}B in the soil and trees as a function of time, and an investigation of the ameliorative effects of Ca on B accumulation and toxicity.

Spur branch leaf samples were collected from a minimum of three trees in each of three to five field replicates at monthly intervals throughout the experiment. Bark, spur branches, and other woody tissue were collected twice per year, while nut meat subsamples were collected from the field harvest each year.

RESULTS: Plant tissue sampling was completed during the 1992 season and field tissue sampling terminated. Tissue samples were collected and most analyses completed for B, Na, and Cl. Visual foliar damage symptoms were assessed across all treatments, with the worst visual damage, as in previous years, consistently occurring in trees which had received saline irrigation water at low leaching fractions during prior seasons. Leaf tip and margin "burn" was also moderate to severe in the saline water microspray irrigated treatment, and much more severe than any slight damage noted in nonsaline microspray or drip treatments. Visual foliar damage was consistently worse in the "Ruby" cultivar, although results indicate similar leaf and stem B concentrations in leaves of both cultivars. Leaf and stem Cl concentrations analyzed to date indicate consistently higher Cl levels and slightly higher Na levels in saline-irrigated trees of the Ruby cultivar as compared to the Butte cultivar.

In analyses both at WMRL and UCD, it was found that the concentrations of B were consistently highest in fruit (in excess of 200 to 400 mg/kg in hulls in late season), with significantly lower B concentrations in leaves (generally less than 70 to 80 mg B/kg dry weight) and spur branches (less than 80 mg/kg) in the late season (July – August). Concentrations of B were quite variable across the season in leaf and stem tissue, with gradual increases in leaf B concentrations and slight reductions in stem B concentration during most of the season (April through August) followed by a rapid reduction to less than 30 to 50 mg/kg during the harvest/leaf fall period. In leaf, stem, and fruit tissue, higher tissue B levels prevailed in treatments which received saline irrigation water during seasons prior to 1991.

In trees with extreme foliar damage, spur branches and tip die–back of branches was also observed, with progressive necrosis of leaves and small branches starting at the outer edges of west– and south–facing branches. Foliar damage in saline–irrigated trees was most highly and positively correlated with increases in leaf and spur branch sodium levels, but was also positively correlated with accumulations of boron. Chloride accumulations in leaf tissue were highly variable within the tree canopy according to leaf position.

Comparison of saline, microspray–irrigated trees with drip–irrigated trees receiving the same quality water consistently showed higher tissue Na, B, and Cl levels in microspray irrigated trees. This is undoubtedly due to the lower amounts of leaching, greater evaporation losses under microspray which result in greater accumulation of these constituents in the upper root zone.

FUTURE PLANS: This experiment was terminated at the conclusion of the 1992 season. UC Davis personnel conducted evaluations of potential inter–actions between applied Calcium and resulting B accumulation and toxicity during 1992, and those chemical analyses are in progress. Several manu–scripts will be prepared based upon these analyses.

ACCURACY OF ET_o ESTIMATES FROM AUTOMATED CLASS-A PAN EVAPORATION MEASUREMENTS

C.J. Phene, D.A. Clark, A. Marani, and M. Norman

OBJECTIVES: To determine the accuracy of daily ET_o estimated from automated screened and non-screened Class-A pan evaporation measurements, and compare results to direct evapotranspiration of cool season grass measured by a nearby precision weighing lysimeter.

PROCEDURES: Two class-A evaporation pans (galvanized, 20 gauge steel) were installed at Five Points, California on wood palettes, as described in original US Weather Bureau installation procedures for the Class-A evaporation pan. The water level in each pan was monitored continuously by an electronic level sensor (Model MN-2, BCP Electronics, Clovis, CA) and recorded hourly by a data acquisition and control system (DACS) (Model 21X, Campbell Scientific Inc., Logan, UT). One evaporation pan was fitted with a screen (Model HM020, BCP Electronics, Clovis, CA) to protect the pan from wild animals and birds and to reduce the evaporation to a value closer to ET_o. Both pans were refilled automatically at midnight to a constant level, approximately 25 mm from the top of the pan. Accumulated data were transmitted automatically via telephone to the WMRL office at 05:00 (PST) daily. The weighing grass lysimeter is located approximately 50 m north of the pan/weather station system and both systems are located in the middle of an irrigated grass field, 100 x 150 m. The grass lysimeter has a surface area of 4 m^2, a depth of 2.35 m and an evapotranspiration resolution of 0.02 mm/h. The grass in the lysimeter and the immediate areas around the pan and the lysimeter are irrigated several times daily and cut at least once weekly.

RESULTS: Figure 1 shows the daily relationship between data from the weighing grass lysimeter (abscissa) and the two evaporation pans (ordinate) for a period of 30 days in 1991. The 1:1 relation line is shown for comparison purposes and does not imply a regression analysis for these data. This data set was chosen because it covers a broad range of evaporation measurements (4.0–8.2 mm for the lysimeter and 4–13 mm for the two pans). For the screened evaporation pan, 27 out of 30 days were between +/– 1.0 mm of the lysimeter data, whereas the "open" pan data are generally about 3 mm above the 1:1 line. Previous analyses and comparisons of evaporation from pans with ET_o calculated from weather station instruments have shown that this screen can reduce evaporation from 10 to 15% depending on sitting but does not necessarily improve the correlation of the measurements. However, if screened pan evaporation can estimate ET_o as well as an ET model using automated weather station measurements, it is advantageous because it is easier to install, it requires less instrumentation and maintenance than a weather station and it can be used directly as a feedback control element in an automated irrigation control system. However, a pressurized water source must be available so that the pan can be refilled daily.

FUTURE PLANS: A model is being completed and tested to correct for the effect of ambient temperature on the heat and mass balance of the pan and to correct for the effect of temperature on the lag time it induces on hourly ET_o estimates. Publications are in process.

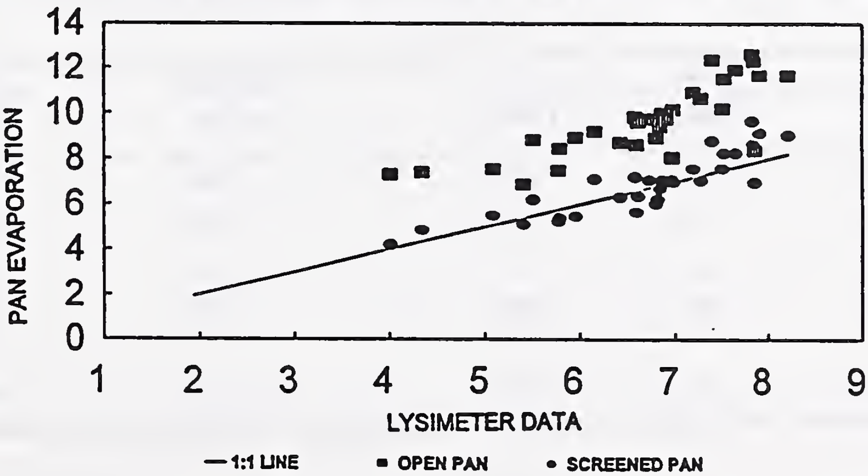


Figure 1. Relationship of Et_o and Pan evaporation (mm/day) obtained at Five Points, CA, in 1991.

FIELD DEMONSTRATION OF EMERGING IRRIGATION TECHNOLOGIES FOR COTTON SUBSURFACE DRIP IRRIGATED, LEPA, AND FURROW IRRIGATION SYSTEMS

C.J. Phene, R.M. Mead, D.A. Clark, B. Freeman,
S. Styles, J. Frost, and J.D. Oster

OBJECTIVE: To evaluate and compare a subsurface drip irrigation (SDI) system to other traditional irrigation systems on a large scale, specifically ones that are used on annual row crops such as cotton.

PROCEDURE: An irrigation project at Harris Farms (near Coalinga, CA) was developed on a 65 ha field. Four treatments were chosen; LEPA (low energy precision application), historic furrow (400 m runs), improved furrow (200 m runs with a tail water return system), and subsurface drip irrigation (SDI). Each treatment was approximately 16.2 ha in size.

In the early winter of 1989, drip tubing was installed 45 cm below the average soil surface of the NW quadrant. Laterals were spaced 2 m apart with each emitter having an output of 2 l/h. Cotton was planted in the first two years followed by cantaloupe in 1991. In 1992, cotton was planted on April 7. An automated class A evaporation pan was installed about a month later and used as a feedback irrigation controller.

Cotton crop coefficients were incorporated into a CR10 data logger linked to the evaporation pan. Using the automated evaporation pan with the crop coefficients, an irrigation threshold of 1.0 mm was used and triggered the irrigation pump to deliver the same amount of water to the field.

RESULTS: Due to saline conditions of the drip plots, there was 195 mm of water applied to the field for pre-irrigation purposes. During June, July and August a total of 427 mm was applied to the SDI plots. The LEPA, improved and historic furrow treatments received 439, 509, and 500 mm, respectively.

Cotton was defoliated on September 15 and harvested on October 8. It was estimated that the drip irrigated cotton extracted 153 mm of water from the water table and soil profile.

The SDI plots out-yielded all other treatments (see Table 1). It is not known if the extra amount of pre-irrigation had any significant impact on cotton yield.

Overall, the automated irrigation scheduling using the pan/data logger/pump control system worked very well with some exceptions of having the pond source becoming too low at critical times.

FUTURE PLANS: A more uniform pre-irrigation for all treatments will be insured for 1993. Phosphoric acid will be continuously injected through the drip system at 15 ppm P. The drip irrigation water source will be continuously monitored for salinity (EC_1).

Table 1. Irrigation amounts, yields. and net income for SDI, LEPA, historic and improved furrow irrigation systems.

System	mm Pre	mm Season	mm Total	Lint Yield kg/ha	Net Income $/ha
SDI	195	427	622	1720	572
LEPA	58	439	497	1488	694
Historic furrow	0(?)	500	500	1483	782
Improved furrow	58	509	567	1538	981

UNIFORMITY EVALUATION OF SUBSURFACE DRIP IRRIGATION SYSTEMS AT HARRIS FARMS, COALINGA, CA

R. Yue, C.J. Phene, J. E. Ayars, I-Pai Wu

OBJECTIVES: The evaluation results at 30 Acres, Britz Farms, UC West Side Field Station and USDA Irrigated Desert Research Station showed that, models EGL, REGL and SBS can be used to perform the uniformity evaluation on drip irrigation systems. Please refer to the separate reports for details on those evaluations. Thus, the purpose of this study is to evaluate the uniformity of subsurface drip irrigation systems installed at Harris Farms, Coalinga, CA, with the three models.

METHODS: The uniformity of the subsurface drip systems will be evaluated by models EGL, REGL and SBS. The system was installed in 1989. Netafim in-line emitter with 0.4 GPH nominal flow rate is used. The emitters were spaced at 40 inches along 0.52 inches I.D. polyethylene tube. The drip tubes, or laterals, are buried 18 inches deep, and have a length of 450 feet. The lateral spacing is 80 inches. There are two submain units. The length of each submain is about 1350 feet. The submain size is 4 inches. There are laterals along the two sides of one submain. The other submain controls laterals on one side only.

RESULTS: Model simulation results are given in Figure 1 and 2. For the submain units with laterals along one side of the submain, the three models have similar simulation results, with a UC of about 96%, a CV of 4% to 6%, and a q^{var} of 25% to 30%. This means that the submain unit has a high water distribution uniformity. For the submain unit with laterals along both sides of the submain, REGL and SBS models have the similar results, while the results of EGL are quiet different from the ones of either REGL or SBS model. The submain unit has a UC of about 90%, a CV of 11 to 13%, and a q_{var} of 40 to 42% base on REGL or SBS model simulation results. EGL model simulation results show that this submain unit seems to have a UC as low as 63.41%, a CV as high as 42.18% and a q_{var} as high as 75.88%. Uniformity evaluations on the four locations mentioned in OBJECTIVES section showed that simulation results from REGL and SBS models are quiet near to field test results. The larger the size of a submain unit, the bigger the difference between EGL model simulation results and field test results. Based on REGL and SBS simulation results, it can be concluded that:

1. the submain unit with laterals along one side of the submain has a UC of 96%, an average emitter flow rate of 0.53 GPH and the water pressures are ranged from 18 to 25 psi;

2. the submain unit with laterals along both sides of the submain has a UC of 90%, an average emitter flow rate of 0.45 GPH and the water pressures are ranged from 10 to 25 psi.

OUTPUT MENU

CEDDIS 5.5

**** GIVEN INFORMATION ****

SUBMAIN		LATERAL		EMITTERS	
Pressure(psi)=	25.00	Spacing(ft) =	6.67	Spacing(ft) =	3.33
Length(ft) =	1320.00	Length(ft) =	450.00	Constant k =	0.1210
Diameter(in) =	4.072	Diameter(in)=	0.520	Exponent x =	0.4926
Constant K =	10.461	Constant K =	10.461	ManufactureCv=	2.50
Friction C =	150	Friction C =	150	Plugging % =	0.00
Exponent M =	1.8520	Exponent M =	1.8520	P-Percent =	0.00
Slope(%) =	0.00	Slope(%) =	0.00	P-Degree(%) =	0.00

Lateral Distribution pattern along the submain: 1

*********************** RESULT FOR THE SUBMAIN UNIT ***********************

MODEL	UC (%)	CV (%)	Qvar (%)	qmax (GPH)	qmin (GPH)	qavg (GPH)	hmax (psi)	hmin (psi)	havg (psi)
EGL	95.64	5.40	28.89	0.627	0.446	0.511	25.000	16.550	18.643
REGL	96.38	4.51	25.91	0.629	0.466	0.526	25.000	18.076	19.812
SBS	96.50	4.37	25.71	0.628	0.467	0.527	24.999	18.128	19.823

Simulation including: Hydraulics, Manufacture Variation

F1-Help F2-Analysis F3-Switch Units Esc-Exit

Figure 1. Evaluation Results for the Submain Unit with Laterals along One Side of the Submain.

OUTPUT MENU

CEDDIS 5.5

**** GIVEN INFORMATION ****

SUBMAIN		LATERAL		EMITTERS	
Pressure(psi)=	25.00	Spacing(ft) =	6.67	Spacing(ft) =	3.33
Length(ft) =	1320.00	Length(ft) =	450.00	Constant k =	0.1210
Diameter(in) =	4.072	Diameter(in)=	0.520	Exponent x =	0.4926
Constant K =	10.461	Constant K =	10.461	ManufactureCv=	2.50
Friction C =	150	Friction C =	150	Plugging % =	0.00
Exponent M =	1.8520	Exponent M =	1.8520	P-Percent =	0.00
Slope(%) =	0.00	Slope(%) =	0.00	P-Degree(%) =	0.00

Lateral Distribution pattern along the submain: 2

*********************** RESULT FOR THE SUBMAIN UNIT ***********************

MODEL	UC (%)	CV (%)	Qvar (%)	qmax (GPH)	qmin (GPH)	qavg (GPH)	hmax (psi)	hmin (psi)	havg (psi)
EGL	63.41	42.18	75.88	0.613	0.148	0.297	25.000	1.761	7.359
REGL	89.33	12.68	41.78	0.617	0.359	0.444	25.000	10.654	14.254
SBS	90.87	11.02	40.00	0.616	0.370	0.449	25.000	11.288	14.520

Simulation including: Hydraulics, Manufacture Variation

F1-Help F2-Analysis F3-Switch Units Esc-Exit

Figure 2. Evaluation Results for the Submain Unit with Laterals along Two Sides of the Submain

SUBSURFACE DRIP IRRIGATION OF YOUNG PRUNE TREES

R.M. Mead, C.J. Phene, D.A. Clark, G. Cardon, K. Schakel, and B. Lampinen

OBJECTIVES: To evaluate the use of a subsurface drip irrigation system (SDI) installed in a young prune orchard and compare it to a surface drip irrigation system.

PROCEDURE: A nine acre block of French Prune trees was planted in February 1991. Tree spacing was 5.2 m between rows and 4.3 m between trees. A surface drip irrigation system was initially installed to conduct fertigation experiments. The surface system consisted of two 4 L hr^{-1} in-line turbulent flow emitters per tree.

In late March 1992, a subsurface drip system (SDI) of 1200 m of (Geoflow Rootguard, 13 mm diameter) drip tubing was installed 45 cm below the soil surface of the orchard to make up the sixth treatment. The drip line was placed 50 to 60 cm west of the North-South tree line. The SDI laterals have a discharge rate of 2 L hr^{-1} per emitter with emitter spacing of 75 cm.

In May 1992, four soil matric potential sensors were installed approximately 40 cm deep and 68 cm west of the four centrally located trees in the North-South tree line. These sensors were installed for monitoring soil responses and with the potential for scheduling orchard irrigations. In 1992, orchard irrigations (for SDI plots) were accomplished using an automated class"A" screened pan in conjunction with an estimated crop coefficient (K_c). The threshold for irrigations was 1 mm. A fertilizer injector (Dosatron, Model D8R) was used to inject UN 32 for N (0.06 kg N/tree) and green phosphoric acid for P (0.045 kg P/tree) in the SDI plots. UN 32 for N was also used for other treatments (0.45, 0.23 and 0.11 kg N/tree) as part of the fertigation experiment.

RESULTS: From June 12 to October 19, 462 mm of water was delivered to the SDI plots (see table 1). Based on estimated K_c with screened pan evaporation data, ET_c was estimated to be 390 mm. Soil matric potential sensors recorded the driest readings in June (–0.329 J/kg for a monthly average) which got increasingly wetter throughout the season (–0.038 J/kg by October).

Leaf analysis from leaves sampled in July showed that the SDI treatments had significantly lower N levels than the other three fertilizer N treatments. All other N treatments were appreciably higher than the 0.06 kg N/tree level applied through the SDI system. The water stress in May along with the lower fertility levels could have impacted prune tree growth in the SDI treatment. There was a significant 3.5 cm^2 reduction in cross sectional area which occurred in the SDI plots vs the high fertility treatment (see table 2). No fruit yield was taken due to immaturity of the trees.

FUTURE PLANS: Due to inevitable increases in shade from growing prune tree canopy, the evaporation pan will have to be moved from underneath the trees or raised to the canopy level. The soil matric potential sensors could eventually be used for controlling irrigations.

Table 1. Pan evaporation (Ep), calcualted crop evapotranspiration (ET_c), applied water, mean soil matric potenital (SMP) and crop coeficients (ET_c/Ep) for a prune orchard irrigated by subsurface drip irrigation in 1992.

Month	Ep(mm)	ET_c(mm)	Applied water(mm)	Ave. SMP	ET_c/Ep
June	89.1	29	18.9	–0.329	0.324
July	245	101	146.5	–0.061	0.409
Aug.	258	129	163	–0.05	0.499
Sept.	185	85	102	–0.045	0.46
Oct.	66	21	31	–0.038	0.326
Nov.	64	25		–0.144	0.39
Total	907.1	390	461.4		

Table 2. Measurement of prune tree growth expressed in tree trunk cross sections area (cm^2).

Treatment	x-section (cm 2)
Surface Drip – No N	21.0 ab*
Surface Drip – (1 lb N/tree)	22.1 a
SDI (0.06 kg N/tree)	18.6 b

*Duncans multiple range at 5%.

INFLUENCE OF CALCIUM ON THE UPTAKE OF BORON IN *BRASSICA JUNCEA*

G.S. Bañuelos, S. Downey, R. Mead, S. Akohoue, and S. Zambrzuski

OBJECTIVE: To evaluate different levels of calcium (Ca) on the uptake of boron (B) in plants grown in water culture.

PROCEDURE: Indian mustard is being considered as a partial strategy to remediate boron-laden soils. Its efficiency in removing B by plant uptake may be influenced by the Ca level in the root zones. Greenhouse water-culture experiments were conducted to study B uptake at three different levels of Ca in *Brassica juncea* (Indian mustard). The plants were grown in 4 L pots filled with 0.3 modified Hoagland nutrient solution No. 2 and pH adjusted between 6.3 – 6.7 with minute additions of HCl or KOH, as needed. Containers were kept in a temperature controlled greenhouse at 21°C day and 18°C night temperature with a average light flux of 850 μmol $m^{-2}s^{-1}$ from cool white fluorescent lamps for 12 h. After a period of plant adjustment (5–7 d later), the nutrient solution was replaced with the following treatments; B treatment (<1 and 15 mg B L^{-1}, added as H_3BO_3) and Ca treatment (20, 120, and 400 mg Ca L^{-1}, added as $CaNO_3$) (NH_4NO_3 was added to low and medium levels of Ca). The synthetic salt solution was replaced every 5 d. Deionized water was added to the pots daily to replace water lost by transpiration and to maintain the original volume. The design structure was completely randomized with at least 8 pots per treatment (each pot contained 4 plants). The experiment was repeated four times. Plants were harvested after a 45 d growth period in treatment solution and separated into young and old leaves, top and bottom portion of stem, and roots. Samples were acid digested with HNO_3/H_2SO_4 and B determined with a Perkin Elmer 2000 Inductive Coupled Plasma Emission Spectrometer, while Ca was analyzed by atomic absorption spectrophotometry after dry ashing.

RESULTS: Samples are currently being analyzed for B and Ca. Preliminary data are shown in Table 1.

FUTURE PLANS: Complete Ca and B analyses. Based on the results, a field study will be conducted in soil naturally high in soil B.

Table 1. Limited available data on the accumulation of Ca and B in different organs of *Brassica juncea**

Plant organ	Ca-Treatment level	Concentrations of: Ca (%)	B (mg kg^{-1}DM)
Old Leaves	low	1.2	650
	med.	2.0	490
	high	3.6	440
Upper Stem	low	0.7	260
	med.	1.1	275
	high	2.1	320
Lower Stem	low	0.6	380
	med.	1.3	420
	high	4.2	250

*Values represent the mean concentration from a minimum of 30 plants from only one experiment. Young leaves have not been analyzed.

IN SEARCH OF BRASSICA AND SALT-TOLERANT GERMPLASM IN SALINE SEMI-ARID AND ARID REGIONS OF INDIA AND PAKISTAN FOR BIOREMEDIATION OF SELENIUM LADEN SOILS

G.S. Bañuelos, D. Dyer, R. Akmad, S. Ismail, R.N. Raut, and J.C. Dagar

OBJECTIVE: To collect germplasm native to Pakistan and India for use in removing Se by plant uptake in saline agrosystems.

PROCEDURE: *Brassica juncea* (Indian mustard) is the primary ecotype cultivated in the north and northwestern part of India (Fig. 1) and in the northeastern part of Pakistan (Fig. 2). It is grown primarily for the production of vegetable oil green supplemental fodder and seed cake for animals. Since there is enormous variability within each species of *Brassica* in the form of sub-species and ecotypes, collecting *Brassica* or other salt-tolerant germplasm from saline soil sites within Pakistan and India may be useful in selecting the most efficient salt-tolerant cultivars for vegetation management in removing Se from saline soils of central California. *Brassica* and other species collected from different regions and germplasm storage banks within Pakistan and India will be evaluated for their ability to absorb Se under different salinity levels (5-20 dSm^{-1}) in selected California soils.

RESULTS: In conjunction with agricultural scientists from Pakistan and India the depicted *Brassica* species and other species were collected and returned to the USA (Table 1).

FUTURE PLANS: Screen collected germplasm for tolerance and its ability after planting to absorb S.

Table 1a. Species collected in Pakistan:
*Brassica juncea, B. Carinata, *Panicum turgidum, *Sporobolus airoides, *Leptochloa fusca, *Sesbania sesban, *Atriplex halenius, *A. nummularia, *A. undulata, *A. stocksii, *A. canescens, *A. lentiformis, A. amnicola, Suaeda nudiflora, Salicornia indica, Cassia obovata, Chrysopogon aucherii, Desmostachya bipennata, Terminaolia cattapa, Halocnemium strobilaceum, Riccinis communis.*

Table 1b. Species collected in India:
*Brassica carinata (17 accessions), B. napus (10 accessions), B. esuca ativa (5 accessions), B. juncea (10 accessions), Sporabolus marginatis, Suaeda fruticosa, S. maritima, *Parthmum arienatum, *Leptochloa fusca, *Triticum aestivum, *Echinochloa frumentacea, *E. colonum, *E. crusgalli, *Panicum antidotale, *Bracharia mutic, *Acacia nilotica, *A. leucocephola, *A. farnesiana, *Prosopis juliflora, *P. cineraia, *Sesbania aculeata, *Suaeda fruticosa, *S. maritima, *Kochia indica, *Desmostachya bipinnata, *Casuarina equesetfolia, *Tamarixggalica, *Chloris gayana.*

**Collections were made by In-country scientists and sent to USDA.*

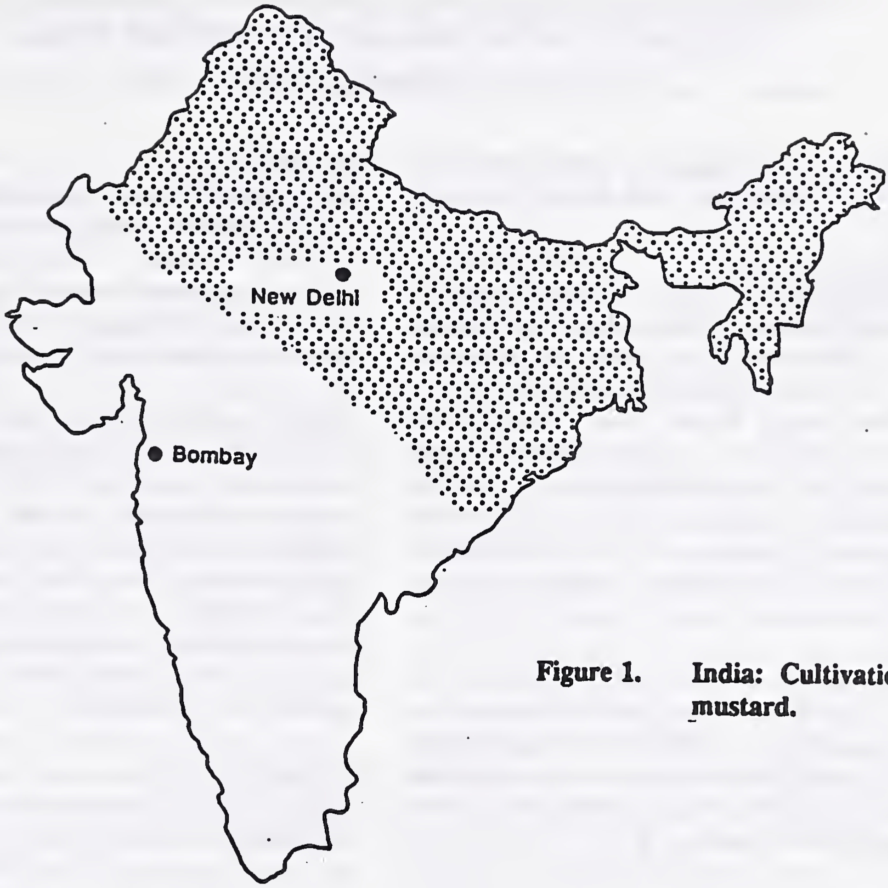


Figure 1. **India: Cultivation area for mustard.**

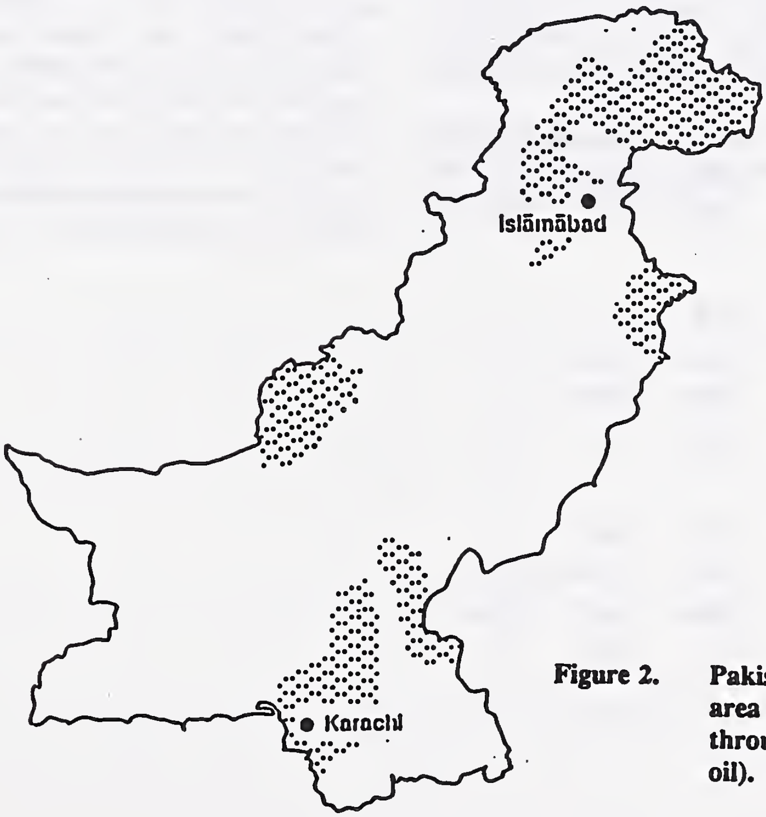


Figure 2. **Pakistan: Main cultivation area for mustard (grown throughout the country for oil).**

COMPARISON OF MICROWAVE DIGESTION WITH BLOCK DIGESTION FOR SELENIUM AND BORON ANALYSIS IN PLANT TISSUES

G.S. Bañuelos, S. Akohoue, and T. Pflaum

OBJECTIVES: To evaluate microwave digestion on the recovery of selenium and boron in plant materials.

PROCEDURES: Selenium (Se) was determined after wet acid digestion using a Thermo Jarell Ash Atomic Absorption Spectrophotomer equipped with an automatic vapor accessory and boron (B) after wet acid digestion using a Perkin Elmer Plasma 2000 Emission Spectrometer. Both elements were determined in NIST Standard Reference Material for both Se and B and 20-mesh dried *Brassica juncea* (Indian mustard) after samples were digested from both microwave and digestion block with the following procedures:

Microwave digestion
A total of fifty 120 ml teflon digestion vessels were placed in the microwave. Different combinations of HNO_3, H_2O_2, and HCl were used as the chemical reagents in conjunction with the following power settings for the microwave:

	Parameters:	Stages I	II	III	IV
1)	Power	50%	90%	0	--
	Time	5 min.	8 min.	10 min.	--
	Fan	100%	100%	100%	--
	PSI	150	150	0	--
2)	Power	50%	90%	0	--
	Time	15 min.	30 min.	30 min.	--
	Fan	100%	100%	100%	--
	PSI	150	150	0	--
3)	Power	85%	85%	85%	0
	Time	6 min.	6 min.	17 min.	0
	Fan	100%	100%	100%	100%
	PSI	40	85	120	0

Block digestion
Using a nitric acid-hydrogen peroxide procedure, plant material was digested by wet acid digestion on the block digestor. Calibration standards were checked throughout the analyses and were required to be within 5% variance of the known values. If 5% was exceeded, the standards were rerun.

RESULTS: Preliminary results clearly show that the block digestion of NIST samples resulted in a recovery of at least 94% of the reported Se and B concentrations, while the most accurate procedure for microwave digestion resulted in a 91% recovery of reported NIST concentrations and 80% of the reported NIST Se concentrations. However, microwave digestion of samples was completed in less than 60 minutes, whereas block digestion of samples required more than 8 hr.

FUTURE PLANS: Continue evaluating data acquired from microwave digestion. A manuscript will be prepared.

TRACE ELEMENT COMPOSITION OF DIFFERENT PLANT SPECIES USED FOR REMEDIATION OF BORON-LADEN SOILS

G.S. Bañuelos, L. Wu, S. Akohoue, S. Zambrzuski, R. Mead, and A. Downey

OBJECTIVES: Evaluate the concentrations of selected trace elements in four plant species used to manage naturally occurring B in the soil.

PROCEDURES: High concentrations of trace elements are often found in conjunction with B and Se in same soils of the westside of central California. Some plant species accumulate not only B, but may accumulate other trace elements also present in the soil. A multiple year field study is being conducted on Three Way Farms near Los Banos, California, to evaluate the uptake of zinc (Zn), cadmium (Cd), manganese (Mn), iron (Fe), aluminum (Al), copper (Cu), and molybdenum (Mo) in soil containing high concentrations of extractable B. The treatment design was a complete randomized design with each treatment replicated eight times in 30 m^2 plots. Treatments consisted of growing the following plant species: *Brassica juncea* (Indian mustard), *Festuca arundinacae* (tall fescue), *Lotus corniculatus* (birdsfoot trefoil), and *Hibiscus cannabinus* L. (kenaf). Irrigation scheduling and application rates for the sprinkler system were based on data collected from CIMIS weather station. Soil moisture was monitored at different depths with weekly neutron probe readings. The mean amount of water applied during the growing season for 2 years was 845 mm, while the mean Class "A" pan losses for both years were 1000 mm. Sixty, 85, and 115 d after first emergence, the perennial plant species were clipped, while Indian mustard was harvested at day 85 and kenaf at day 115. Subsamples of each species were taken from 4 one-meter sections in each plot. Plants were separated into leaves, stalk, and when applicable, roots. A Perkin Elmer Plasma 200 Emission Spectrometer was used to detect for Mn, Fe, Cd, Mo, Al, Cu, and Zn after dry ashing plant samples. Detailed descriptions of the analytical results are presented elsewhere.

RESULTS: The absorption of trace elements by different plant species is highly dependent on the species of the respective element in the soil and pH changes in the soil. In general, the leafy Indian mustard and kenaf had the highest concentrations of each tested element followed by the two perennial crops, tall fescue and birdsfoot trefoil (Table 1). For this reason, if the harvested plant material is to be utilized as animal forage, species of Indian mustard and kenaf should not be fed directly to animals. The following are the ranges for each trace element analyzed: Fe, 70–350 mg Fe kg^{-1} DM; Cd, 1–26 mg Cd kg^{-1} DM; Cu, <10 mg Cu kg^{-1} DM; Al, 70–444 mg Al kg^{-1} DM; Mn, 34–245 mg Mn kg^{-1} DM; and Zn, 2.44 mg Zn kg^{-1} DM. Trace element concentrations are shown in Table 2 for the repeated clippings of the perennial crops.

FUTURE PLANTS: Repeat field planting and monitor trace element concentrations. A manuscript is currently being prepared.

Table 1. Concentrations of selected trace elements in shoot tissue of four plant species grown in 1990 and 1991.

Species	Zn	Cd	Mn	Fe	Al	Cu	Mo	B	Se
	Elemental concentrations of: (mg kg^{-1} DM)								(μg kg^{-1} DM)
1990†									
Kenaf	39(1.0)a‡	18(0.3)a	198(4.4)a	322(12)a	395(15)a	9(0.3)a	1.0(0.1)a	788(44)a	515(36)b
Indian mustard	29(0.7)b	13(0.3)b	39(1.9)b	167(8.5)b	164(12)b	4(0.3)bc	0.4(0.1)b	224(10)b	1062(27)a
Tall fescue	1.4(0.2)c	<1c	43(2.4)b	74(2.7)c	81(4.4)c	1(0.2)c	<0.1c	85(7.9)c	169(10)c
Birdsfoot trefoil	0.6(0.1)d	<1c	34(2.4)b	103(6.3)c	89(4.2)c	5(0.4)b	<0.1c	116(4.2)c	366(24)b
1991									
Kenaf	44(0.9)a	26(0.9)a	245(6.7)a	385(19)a	444(25)a	12(0.2)a	0.9(0.1)a	685(39)a	491(25)b
Indian mustard	22(0.8)b	17(0.6)b	56(3.2)b	156(10)b	189(11)b	5(0.2)b	0.3(0.2)b	321(12)b	989(20)a
Tall fescue	0.9(0.4)c	<1c	50(2.6)b	93(6.4)c	72(3.2)c	1(0.3)c	<0.1c	113(10)c	141(10)c
Birdsfoot trefoil	0.4(0.1)d	<1c	40(3.1)b	90(4.2)c	70(2.6)c	6(0.2)b	<0.1c	118(9.4)c	276(12)d

†Values presented represent means followed by standard error of mean in parenthesis from a minimum of 20 samplings in 1990 and 17 samplings in 1991.

‡Mean separation in columns with years obtained by Tukey's range test. The same letters represent no significant difference in elemental concentrations between species at the P=0.05 level.

Table 2. Trace element concentrations in the different clippings of tall fescue and birdsfoot trefoil grown in 1990 and 1991.

Species	Cut†	Zn	Cd	Mn	Fe	Al	Cu	Mo	B	Se
		Elemental concentrations of: (mg kg^{-1} DM)								(μg kg^{-1} DM)
1990‡										
Tall fescue	1									
"	2	1.0(0.1)a§	<1a	33(2.2)a	62(2.3)a	78(4.4)a	4.0(0.2)a	0.1(0.1)a	106(5.1)a	202(16)a
"	3	1.1(0.1)a	<1a	55(2.4)b	64(2.0)a	66(2.8)a	3.6(0.1)a	0.2(0.1)a	105(7.4)a	283(29)b
Birdsfoot trefoil	1									
"	2	0.4(0.1)a	<1a	31(1.1)a	112(3.4)a	70(2.6)a	4.8(0.4)a	0.3(0.1)a	120(6.8)a	291(8.2)a
"	3	0.6(0.1)a	<1a	66(3.4)b	93(3.8)a	77(3.0)a	4.2(0.4)a	0.6(0.1)b	119(4.5)a	220(6.4)a
1991										
Tall fescue	1									
"	2	0.9(0.1)a	<1a	43(2.7)a	75(2.9)a	82(4.4)a	3.2(0.1)a	0.1(0.1)a	118(6.3)a	182(12)a
"	3	0.8(0.1)a	<1a	68(3.1)b	88(4.1)a	70(3.9)a	3.8(0.1)a	0.1(0.1)a	102(5.1)a	225(16)a
Birdsfoot trefoil	1									
"	2	0.5(0.1)a	<1a	39(3.1)a	69(3.5)a	85(3.6)a	4.2(0.3)a	0.5(0.1)a	126(5.3)a	259(7.1)a
"	3	0.5(0.1)a	<1a	58(2.9)b	72(3.1)a	89(3.2)a	3.8(0.2)a	0.6(0.1)a	118(4.6)a	200(6.4)a

†Values from cut 1 have been presented in Table 2.

‡Values presented represent means followed by standard error of mean in parenthesis from a minimum of 20 samplings in 1990 and 17 samplings in 1991.

§Mean separation in columns with years obtained by Tukey's range test. The same letters represent no significant difference in elemental concentrations between the same species at the P=0.05 level.

SURVEY OF INSECTS ON DIFFERENT CROPS USED FOR BIO-REMEDIATION OF BORON-LADEN SOILS

G.S. Bañuelos, S. Tebbets, S. Zambrzuski, S. Downey and P. Vail

OBJECTIVES: To identify the insects using Indian mustard, tall fescue, birdsfoot trefoil and kenaf as a habitat.

PROCEDURE: A multiple year study is being conducted on Three Way Farms near Los Banos, California to evaluate the quality of insects introduced to a boron-laden field site. The treatment design was a complete randomized design with each treatment replicated three times. Treatments consisted of the following plant species planted on 30 m^2 plots: Indian mustard, tall fescue, birdsfoot trefoil, and kenaf. The plots were sprinkler irrigated with California Aqueduct Canal water (E_c < 0.8 dSm^{-1}). Thirty d after emergence each plot was sampled weekly at 10 A.M. using an insect sweep net. Each sample consisted of eight sweeps progressing from the outside towards the middle of the plot. Collected insects were placed into a glass jar and frozen for later identification.

RESULTS: Preliminary data show the total number of insects found for each species on the different sampling dates (Figure 1). Table 1 show the mean number of insects and arthropods found under the reported headings.

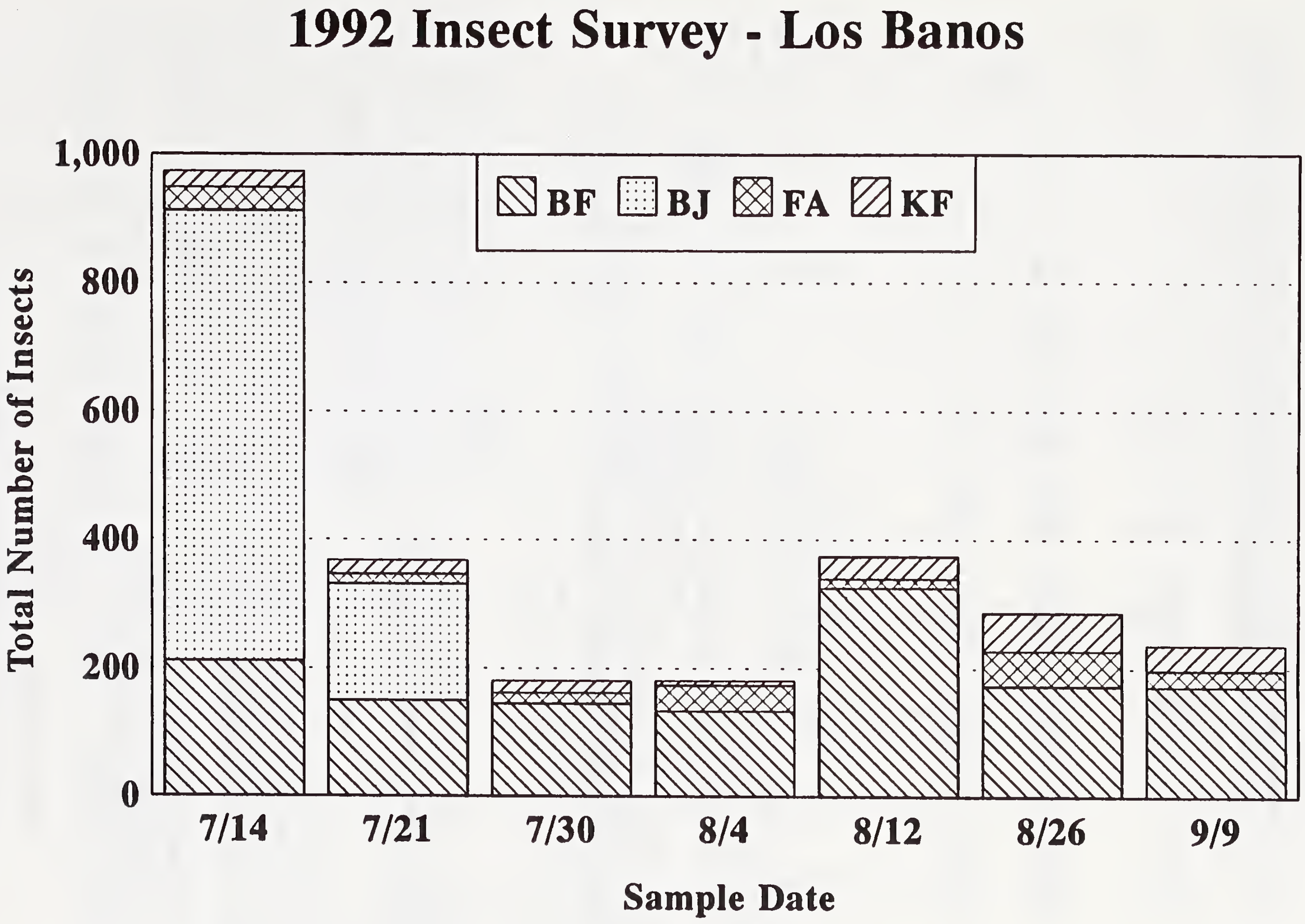
FUTURE PLANS: In-depth identification is currently being pursued. Identification of insects for an additional two years will be conducted. A manuscript will be prepared.

Table 1. Mean number of insects per general classification collected from plots grown to Indian mustard, kenaf, birdsfoot trefoil, and tall fescue*.

		Classification of insects**								
Species	Sampling	bugs	hoppers	beetles	flies	thrips	aphids	wasps	moths	others
Indian mustard	1	688	1	8	2	0	0	0	0	3
"	2	160	3	1	2	3	2	1	0	11
"	3	27	31	5	7	31	80	0	1	45
kenaf	1	9	12	3	0	1	0	0	0	0
"	2	3	50	5	0	0	0	0	0	0
"	3	0	27	3	0	5	0	1	0	3
Birdsfoot trefoil	1	46	24	24	5	91	1	2	1	19
"	2	49	20	11	4	39	1	4	0	22
"	3	37	44	15	4	192	1	3	1	29
Tall fescue	1	2	2	3	2	16	0	2	2	9
"	2	2	1	4	1	3	0	1	1	2
"	3	1	5	1	1	3	0	2	0	4

*Preliminary data of the first screening of insects collected at the respective plots.

**Data represents mean number of insects collected from a minimum of three plots.



BF = birdsfoot trefoil, BJ = Indian mustard, FA = tall fescue, KF = kenaf.
7/14 and 7/21 only for BJ.

REMEDIATING BORON LADEN SOILS WITH TALL FESCUE

G.S. Bañuelos, L. Wu, S. Zambrzuski, S. Akohoue, and S. Downey

OBJECTIVES: To determine the extent to which tall fescue tolerates and absorbs boron (B) in B-laden soil.

PROCEDURES: A multiple year study is being conducted on B-rich soils (up to 10 mg extractable B) on Three Way Farms near Los Banos, California. The treatment design was a complete randomized block with each treatment replicated six times. Treatments consist of "cropped plots" and "uncropped plots". Each plot was 17m x 17m in size. Tall fescue (*Festuca arundinacea*) was planted by drill to a depth of 10 mm at a rate of 10 kg/ha. Access tubes were installed throughout the field site to a depth of 2 m and neutron probe readings were taken every two weeks during the growing in each plot. Prior to planting in spring, four soil samples were collected within each plot to a depth of 0–45 and 45–90 cm. The plots were sprinkler irrigated with California aqueduct Canal Water ($Ec<0.8$ dSm^{-1}) based on data acquired through the CIMIS system. Plants were first clipped every 95 d after first emergence and then 75 d thereafter. Subsamples were first clipped from four 1 m subplots within each plot, dried, and weighed. Both soil and plant samples were analyzed after wet digestion for B and other elements by inductive coupled plasma.

RESULTS: Preliminary data from the first year is shown in Table 1.

Table 1. Preliminary concentrations of total extractable boron and total selenium and mean concentrations of tissue boron and selenium in tall fescue.

Trt.	Rep.**	Depth (cm)	Soil Boron and Selenium Concentrations at:* Preplant Total (mg B kg⁻¹)	Preplant Ext.	Year 1 Total	Year 1 Ext.	Preplant Total (mg Se kg⁻¹)	Year 1 Total	Plant B (mg kg⁻¹)	Plant Se
Tall fescue	1	0–45	58	3.5	54	2.2	1.15	0.95	78	0.66
		45–90	61	4.7	63	4.6	0.95	0.85		
Bare plots	1	0–45	63	4.8	62	4.1	1.25	1.20	*NA*	
		45–90	66	4.5	64	4.9	0.88	0.89		
Tall fescue	2	0–45	54	5.7	50	4.6	0.95	0.75	94	0.78
		45–90	52	6.3	53	5.9	1.24	0.94		
Bare plots	2	0–45	71	4.9	69	4.3	1.45	1.25	*NA*	
		45–90	68	5.1	67	5.3	0.85	0.96		
Tall fescue	3	0–45	49	7.2	45	6.0	1.23	1.01	88	0.86
		45–90	52	6.5	49	6.6	1.31	1.00		
Bare plots	3	0–45	56	5.2	54	4.6	0.79	0.68		
		45–90	59	4.6	61	4.9	0.89	0.93		
Tall fescue	4	0–45	64	9.2	59	7.6	1.13	0.74	85	0.69
		45–90	59	8.3	57	7.9	0.88	0.79		
Bare plots	4	0–45	60	8.6	58	8.2	1.31	1.15	*NA*	
		45–90	56	7.9	54	8.3	1.22	1.33		

*Values represent the mean from a minimum of four replications.
**Replication 5 and 6 have not been analyzed.

THE EFFECT OF SODIUM 2, 3 DICHLOROISOBUTYRATE (DCB) ON THE CARBOHYDRATE PRODUCTION IN INDIAN MUSTARD

G.S. Bañuelos, L.H. Aung, D. Faust, S. Akohoue, S. Downey and S. Zambruski

OBJECTIVE: To determine if DCB promotes biomass of Indian mustard by modifying the production of carbohydrates/soluble sugars.

PROCEDURE: Indian mustard (*Brassica juncea*) was planted on Ramona sandy loam at the USDA facility in Fresno, California, from September to December 1992. The field site was divided into sixteen plots (4 x 14 mm in size) with two treatments; sprayed application of DCB and sprayed application of water (control). Each treatment was replicated eight times. Beds were spaced 1 m apart from center to center. Seed was planted with Planet Jr at a depth of about 2 cm and 15 cm apart. Sprinkler irrigation (80 mm) was used for germination and used only twice thereafter (a total of 140-mm). Thirty d after plant emergence, the DCB plots were carefully hand sprayed with 12 mM DCB, while control plots were sprayed with Tween 20 and water. Careful attention was made to reduce drifting. Seven d later, a second application of 12 mM DCB was applied to the previously treated plots. Forty-five d after the second application of DCB, sixteen plants were harvested from each plot. Samples were washed, separated into the following organs: upper stalk, young leaves, lower stalk, old leaves, and roots, and dried at 45°C for 10 d. For the determination of soluble sugars, the different organs were ground in a stainless steel Wiley mill equipped with a 1 mm mesh screen. One gm samples were extracted with 10 ml of 80% ethanol at 80°C. After extraction, the volume was readjusted to 10 ml and 3 ml aloquats of the supernatants were taken and evaporated to dryness. The dried residues were suspended into 1.5 ml of HPLC-grade water and transferred into 1.5 ml centrifuge tubes. After centrifugation 1 ml of the aqueous solution were filtered prior to the HPLC analysis. Sucrose, glucose, and fructose were qualitatively and quantitatively determined using a Hewlett-Packard HPLC Model 5020. The sugars were separated through a 300 x 7.8 mm Aminex carbohydrate HPX-87C column. The column temperature was maintained constant at 80°C using a Jones chromatography column oven. The solvent was PHLC grade water at a flow rate of 0.7 ml/min.

RESULTS: Preliminary data show a higher soluble sugar content in the "control" plants vs. the DCB treated plants, irrespective of the organ (Table 1). Sucrose was apparently most significantly affected by DCB. Table 1 also shows the distribution of the sugars within the plant.

Table 1.

Treatment	Total soluble sugar content:	Organs: Young stem	Old stem	Young leaves	Old leaves	Roots
		(mg^{-1} DW plant)				
	Sucrose	170	122	81	21	111
Control	Glucose	19	14	8	16	10
	Fructose	26	26	10	5	7
DCB-treated	Sucrose	13	32	16	23	25
	Glucose	3	6	20	9	13
	Fructose	4	11	38	11	10

*Values presented represent the means from five replication.

FUTURE PLANS: Continue the sugar analyses. A manuscript is currently in preparation.

EVALUATE THE EFFECT OF CROP ROTATION ON REMEDIATING BORON LADEN SOILS

G.S. Bañuelos, L. Wu, P. Beuselink, S. Zambrzuski, S. Akohoue, and S. Downey

OBJECTIVES: To determine the extent to which rotating selected annual crop species with perennial species contribute to the reduction of soil B levels.

PROCEDURE: A multiple year study is being conducted on Three Way Farms near Los Banos, California. The treatment design is a complete randomized design with each treatment replicated a minimum of three times on 10 m x 10 m plots. Treatments in the first year 1991 consisted of the following plant species: Indian mustard (*Brassica juncea*), tall fescue (*Festuca arundincea*), birdsfoot trefoil (*Lotus corniculatus*), kenaf (*Hibiscus cannabinis*), and bare plots. In 1992, the first crop rotation occurred. Treatments consisted of: 1) replanting Indian mustard and kenaf in their same plots as planted previously, 2) planting tall fescue in plots planted previously to Indian mustard, kenaf, and tall fescue, 3) planting Indian mustard and kenaf to plots previously planted to tall fescue and birdsfoot trefoil, respectivley, and 4) no plants planted to bare plots. Four soil samples were collected within each plot from the depth intervals of 0–45 and 45–90 cm and repeated in the same location at harvest. Plots were both irrigated and plants clipped as described previously. Plant and soil samples were prepared as described previously and analyzed for total B and extractable B, respectively, by a Perkin Elmer Plasma 2000 Emission Spectrometer.

RESULTS: Preliminary data are shown in Table 1.

FUTURE PLANS: Repeat planting and continue evaluating crop rotations on B and Se removed.

Table 1. Preliminary preplant and postharvest concentrations of soil extractable boron and total selenium and mean concentrations of tissue boron and selenium in different plant species.

Species planted	Species previously planted	Soil Boron and Selenium Concentrations at:*				Plant**	
		Preplant	Postharvest	Preplant	Postharvest	B	Se
		(mg B kg^{-1})		(mg Se kg^{-1})		(mg kg^{-1})	
Indian mustard	Indian mustard	5.8	4.1	1.35	0.85	265	1.14
Kenaf	Kenaf	6.5	5.0	1.05	0.87	675	0.69
Tall fescue	Indian mustard	6.0	5.1	0.94	0.71	85	0.59
Tall fescue	Kenaf	4.9	3.9	1.16	0.89	94	0.63
Tall fescue	Tall fescue	7.1	5.9	4.41	1.20	72	0.68
Indian mustard	Tall fescue	6.5	4.1	0.95	0.68	323	0.98
Kenaf	Birdsfoot trefoil	5.7	4.0	0.88	0.72	709	0.81
Bare plots	Bare plots	6.9	6.1	0.91	0.82	--	--

*Values represent the mean from 12 replications taken from 0–90 cm.

**Values represent the mean concentration in the shoot at cut 1 from 12 replications.

THE EFFECT OF SELENIUM AND INCREASING LEVELS OF BORON AND SALINITY ON THE GERMINATION OF DIFFERENT CULTIVARS OF KENAF

S. Zambrzuski and G.S. Bañuelos

OBJECTIVE: The objective of this study was to evaluate the germination and vigor response of six different cultivars of kenaf exposed to Se and increasing levels of boron (B) and salinity under controlled conditions.

PROCEDURE: Twenty-five seeds from the following cultivars of kenaf (Indian, Iran Early Beso, KU482, KU3876, Egypt, KK60) were placed, respectively, in petri dishes. Seeds, petri dishes, and filter paper were sterilized with a 10% bleach solution and then rinsed with distilled water. Petri dishes were sealed with parafilm and placed under fluorescent lights for 16 hrs per day. Treatments consisted of adding a 4 ml solution containing 10 or 20 mg B/L (added as H_3BO_3); 5, 10, or 20 dS/m salinity (added as NaCl, $CaCl_2$, and Na_2SO_4); 0.5 mg Se/L (added as Na_2SeO_4) (Table 1). Controls contained 4 ml of distilled water. Each treatment was replicated 3 times and the experiment was repeated 3 times. Temperatures were maintained between 20°C and 27°C. After 6–8 days, each cultivar was evaluated for germination, lateral root, and cotyledonary leaf development.

RESULTS: The standard seed germination test did not reflect major differences among cultivars for increased salinity or B levels (Table 2). However, high germination percentages did not always correspond to high seed vigor as was indicated by decreased lateral root and cotyledon development at increased salinity (Figs. 1a, 1b, 2a, 2b). The cv. KK60 shows fairly high seed vigor at the increased salinity levels, however, the germination rates are very low. The cv. Iran Early Beso has a high germination rate, but seed vigor decreases dramatically at the highest salinity levels. The cv. Indian shows a fairly high germination rate as well as high seed vigor at the increased salinity levels. Boron and Se did not show any observable effect on the germination or vigor of the tested cultivars.

Table 1 **The following are the treatments used for germination studies**

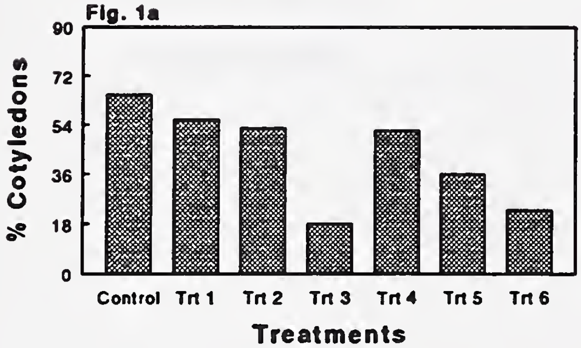
CONTROL	-	Distilled water		
TREATMENT 1	-	0.5 mg Se/L;	5 dS/m salinity;	10 mg B/L
TREATMENT 2	-	0.5 mg Se/L;	10 dS/m salinity;	10 mg B/L
TREATMENT 3	-	0.5 mg Se/L;	20 dS/m salinity;	10 mg B/L
TREATMENT 4	-	0.5 mg Se/L;	5 dS/m salinity;	20 mg B/L
TREATMENT 5	-	0.5 mg Se/L;	10 dS/m salinity;	20 mg B/L
TREATMENT 6	-	0.5 mg Se/L;	20 dS/m salinity;	20 mg B/L

Table 2 **% GERMINATION**

TREATMENTS	INDIAN	IRAN EARLY BESO	KU482	KU3876	EGYPT	KK60
Control	78	97	91	94	94	66
1	76	95	93	93	96	57
2	79	94	82	90	92	56
3	61	71	67	67	71	36
4	78	96	90	90	93	48
5	80	91	89	84	96	56
6	63	75	70	70	68	50

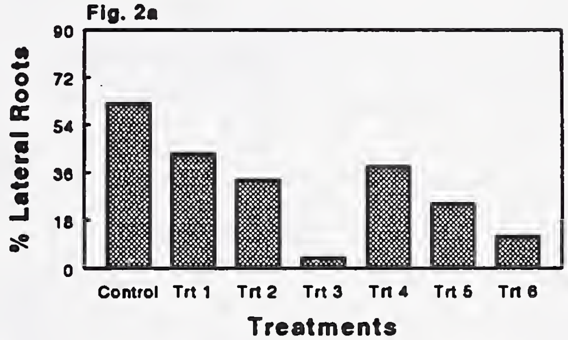
cv. INDIAN

Fig. 1a



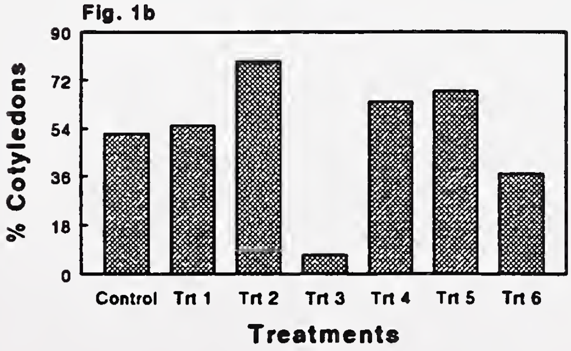
cv. INDIAN

Fig. 2a



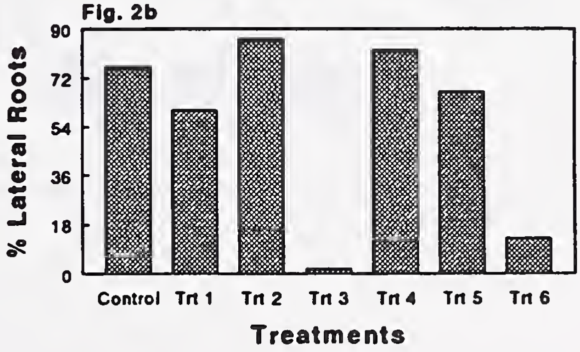
cv. IRAN EARLY BESO

Fig. 1b



cv. IRAN EARLY BESO

Fig. 2b



MANAGEMENT OF SMALL VOLUME-CLOSED SYSTEM HYDROPONICS WITH EMPHASIS ON FACTORS INFLUENCING NUTRIENT SOLUTION pH

S. Downey, G.S. Banuelos, and S. Akohoue

OBJECTIVE: To determine the effects of water loss, ion removal, root exudates and the introduction of compressed air, together and separately, on solution pH and nutrient uptake in a low volume, closed hydroponics system.

PROCEDURES: Greenhouse pot experiments were conducted to evaluate the quality of maintaining desired hydroponic conditions. Seeds from *Brassica juncea* (Indian mustard) were germinated in flats containing vermiculite potting soil. After 10 days they were transplanted into 2 L pots filled with a 0.3 Hoagland nutrient solution. The solution pH was adjusted to 6.2 with addition of 1 M KOH or 10% HCl as needed. The experimental design was a complete randomized block with six treatments, with each treatment replicated three times, and the study was repeated three times. Each treatment consisted of different times for replenishing the nutrient solution. Solution pH was measured before and after refilling with deionized water. Treatments 1 and 2 received fresh nutrient solution on the first day only and thereafter, they were refilled every day with deionized water only. Treatments 3 and 4 were emptied and refilled with fresh nutrient solution every 2 days and filled to full volume with deionized water on alterant days. Treatments 5 and 6 were emptied and refilled with fresh nutrient solution every 6 days and filled to full volume with deionized water on all other days. Solution pH of treatments 1, 3, and 5 was tested before addition of deionized water or nutrient solution and solution pH of treatments 2, 4 and 6 was tested after the addition of deionized water or nutrient solution.

RESULTS: The results of the water culture study indicate that irrespective of treatment, the solution pH increases with time (Trt. 1, 3, and 5 as seen in Fig. 1a, 1b, and 1c). After the addition of deionized water to maintain desired volume, the pH with Trt. 2, 4, and 6 was closer to desired level of 6.2 – 6.6 (Fig. 1a, 1b, and 1c). Moreover, as the levels of ions in solution decreased over time (Fig. 2a), the only ion which clearly responded to changes in pH was Mn (Fig. 2b).

FUTURE PLANS: Future water-culture experiments and desired conditions can be controlled more stringently by replacing evaporative losses daily.

Fig. 1a

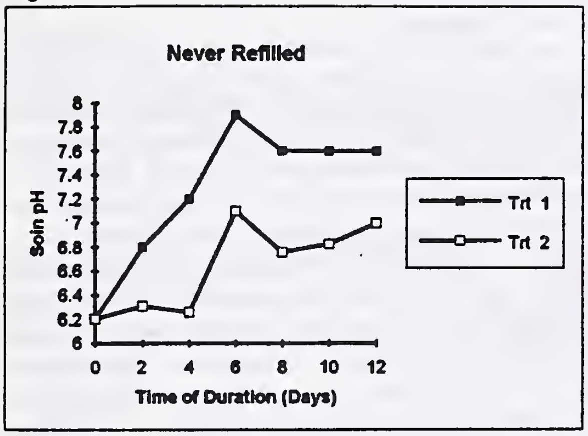


Fig. 1b

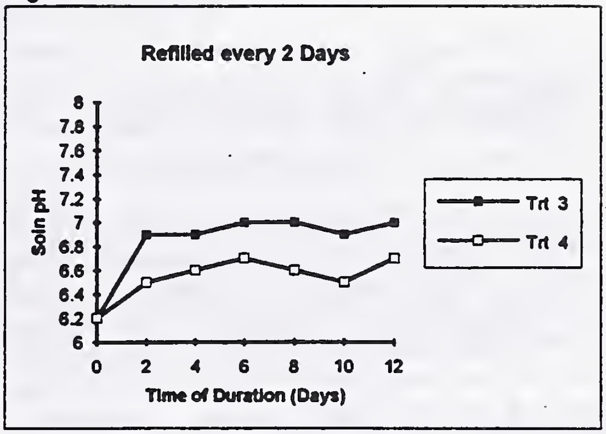


Fig. 1c

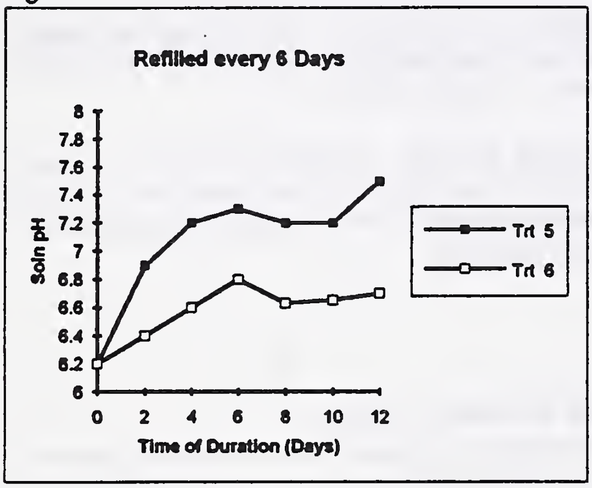


Fig. 2a

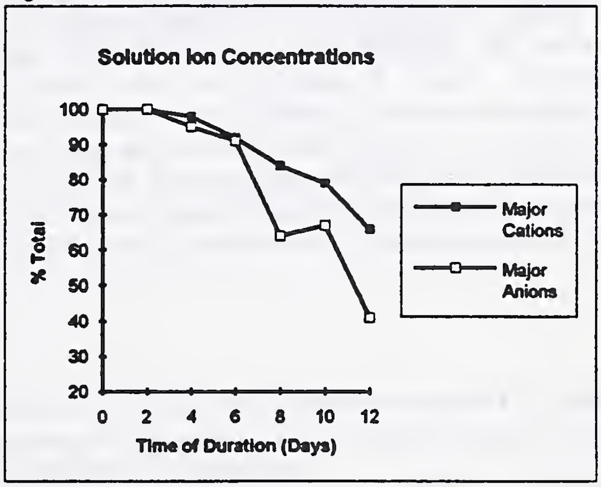
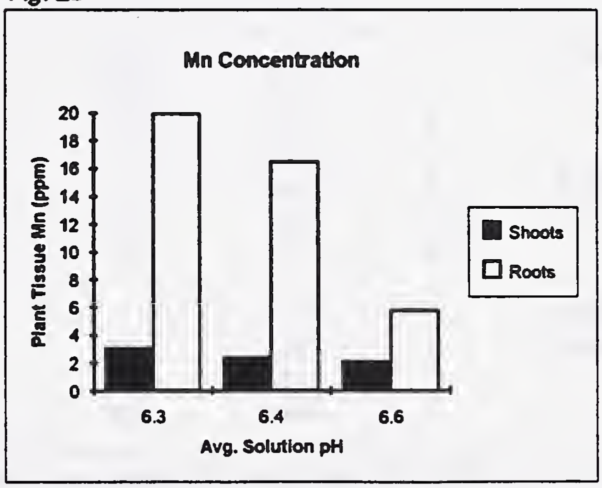


Fig. 2b



COMPARATIVE RATES OF SELENIUM VOLATILIZATION IN THREE PLANT SPECIES

S. Downey, G. Bañuelos, and S. Akohoue

OBJECTIVES: To compare rates of selenium (Se) volatilization in cotton, kenaf and Indian mustard and develop procedures for extracting volatile Se.

PROCEDURES: Seeds of cotton GC 510 (*Gossypium hirsutum*), kenaf (*Hibiscus cannabinis*), and Indian mustard (*Brassica juncea*) were germinated in flats containing vermiculite potting soil. After ten days four seedlings from each species were transplanted into 2 L pots containing soil amended with 2 mg Se/kg soil added as sodium selenate. There were a total of six replicates per species and the experiment repeated three times. Each 2 l pot was placed inside a volatile Se collection chamber which was housed within an environmental growth chamber at different stages of growth for each species. Conditions within the growth chamber were held at a constant 29 degrees C with a photoperiod of 16 hr. light/dark period (850 micromol/m2/sec.). Volatile Se collection chambers were constructed of transparent acrylic and measured 30 cm x 30 cm x 60 cm. Each chamber was equipped with a circulation fan and an exhaust port filled with eight pieces of activated charcoal filter each measuring 7.5 cm x 5 cm. The fan directed the air within the chamber through the charcoal trap and out through the exhaust port, trapping volatilized Se in the activated charcoal. Filters were removed for analysis after 4 days. Volatilized Se was extracted from the charcoal filters by nitric acid/hydrogen peroxide digestion and analyzed for Se by atomic absorption spectrophotometry with continuous hydride generation.

RESULTS: Preliminary results show that Indian mustard volatilized Se at a greater rate than either kenaf or cotton (Table 1).

FUTURE PLANS: Charcoal filter are currently being extracted for Se. The ability of cotton to volatilize Se at different levels of soil Se is currently being conducted.

Table 1. The rate of selenium volatilization by cotton, kenaf, and Indian mustard.

Species	Repeat	Se Concentration at Different Stages of Growth:* First	Second	Third	Fourth	Fifth	Sixth
		(µg Se/plants)					
Cotton	1	14	16	16	15	NC	NC
	2	15	18	13	16	NC	NC
	3	15	16	17	14	NC	NC
Kenaf	1	14	15	17	15	NC	NC
	2	16	18	19	18	NC	NC
	3	17	14	15	17	NC	NC
Indian mustard	1	20	27	32	34	NC	NC
	2	23	30	28	27	NC	NC
	3	26	25	33	27	NC	NC

*Values represent the mean from six replications. Samples were taken every 7 d beginning at day 45 for cotton and kenaf and day 30 for Indian mustard.
NCNot completed.

THE EFFECT OF SELENIUM AND INCREASING LEVELS OF BORON AND SALINITY ON THE GERMINATION OF CANOLA

S. Zambrzuski and G.S. Bañuelos

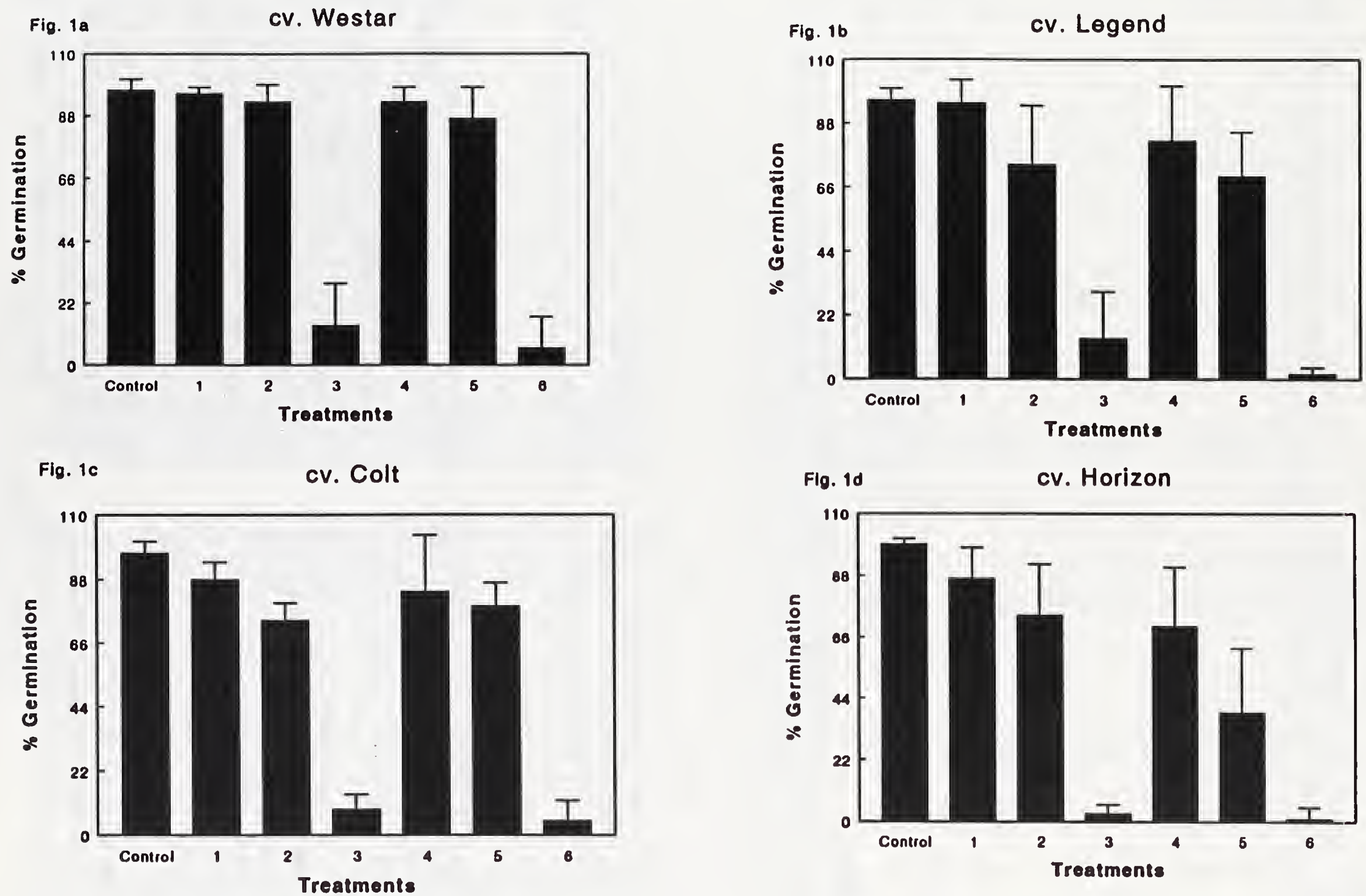
OBJECTIVE: The objective of this study was to evaluate the germination response of four canola cultivars exposed to selenium (Se) and increasing levels of boron (B) and salinity under controlled conditions.

PROCEDURE: Twenty-five seeds from the following cultivars of canola (Westar, Legend, Horizon, and Colt) were placed, respectively, in petri dishes. Treatments consisted of adding a 4 ml solution containing 10 or 20 mg B/L (added as H_3BO_3); 5, 10, or 20 dS/m salinity (added as NaCl, $CaCl_2$, and Na_2SO_4); 0.5 mg Se/L (added as Na_2SeO_4). Controls contained 4 ml of distilled water. Each treatment was replicated 3 times. Petri dishes were sealed with parafilm and placed under fluorescent lights for 16 hours per day. Temperatures were maintained between 20°C and 27°C. After 5 to 8 days, each cultivar was evaluated for germination.

RESULTS: Preliminary data shows with increasing salinity seed germination decreased in all cultivars (Table 1). Westar appeared to be the most vigorous of the four cultivars, showing the highest germination rate with increasing salinity levels. Boron and selenium did not show any observable effect on the germination of the tested cultivars.

FUTURE PLANS: Continue to evaluate the performance of canola under the already discribed conditions. Plant the best performing cultivar under field conditions and evaluate its performance.

Figures 1 a-d. Influence of salinity and boron on the germination rate of different cultivars of canola.



Treatments:

Control	= Deionized water
Treatment 1	= 0.5 mg Se/L; 5 dS/m salinity; 10 mg B/L
Treatment 2	= 0.5 mg Se/L; 10 dS/m salinity; 10 mg B/L
Treatment 3	= 0.5 mg Se/L; 20 dS/m salinity; 10 mg B/L
Treatment 4	= 0.5 mg Se/L; 5 dS/m salinity; 20 mg B/L
Treatment 5	= 0.5 mg Se/L; 10 dS/m salinity; 20 mg B/L
Treatment 6	= 0.5 mg Se/L; 20 dS/m salinity; 20 mg B/L

Note: Bar represents the standard deviation between replications.

SUPPORT LABORATORIES

ANALYTICAL CHEMISTRY LABORATORY

T.J. Pflaum, C.A. Ament, G.S. Banuelos, and B.H. Hagans

The main purpose of the Analytical Chemistry Laboratory is to support field research projects for the Water Management Research Laboratory. The types of samples analyzed include soils, water, and plant tissue. The total number of analyses performed for 1992 was 23,000 on a total number of 5300 samples.

During the year of 1992, 12,700 analyses for cations and anions were performed on a total of 1500 soil samples. In addition to the soil samples, 2500 water and 1300 plant tissue samples were examined for a total of 7000 and 3300 analyses, respectively.

There have been significant changes in the laboratory personnel during 1992. Winnett Pranger-Chin was transferred out of the chemistry laboratory. Colleen Ament was transferred into the chemistry laboratory. During the summer, three high school apprentices served as temporary technicians and were assigned to do the routine analyses on plant, water, and soil samples. The implementation of safety regulations regarding respirator equipment and the necessity for physical examinations has limited the number of technicians who are able to grind plant and soil samples.

There have been changes in the laboratory equipment:

a. The appearance of the chemical laboratory was changed by the installation of a new vinyl floor.

b. A new Electronic Analytical Mettler Balance was purchased. The new Analytical Balance is easier to use and cannot be damaged as easily as the Mettler Analytical Balance. Moreover, another top loading balance for weighing soil samples was purchased.

c. The orion pH/ISE meter was no longer repairable, so a new Orion pH Meter was purchased.

d. A new user friendly direct reading temperature compensated Conductivity Meter was purchased to replace the old Conductivity Bridge for the measurement of electrical conductivity.

e. The Microwave Digestion Unit and the Alpkem Rapid Flow Analyzer were used to determine Total Persulfate Nitrogen in plant tissue. Extra digestion vessels and spare parts for the Alpkem Analyzer were also acquired.

The old Atomic Absorption Spectrophotometer (AA) was controlled by a HP computer, which was having disk drive problems. The disk drives are no longer available and service attempts were futile. To solve this problem, a new Atomic Absorption Spectrophotometer (AA) controlled by an IBM clone computer was purchased.

The laboratory is still in the process of being physically modified to accept the new AA since the old AA will remain in the laboratory. The vent motor for the AA vent failed again and a new vent and motor was purchased locally.

The UV-Visible Spectrophotometer was sent for repairs twice and is aligned and ready for use.

ELECTRONICS ENGINEERING LABORATORY

D. Clark, M. Norman, T. Lockner, T. Polus

The Electronics Engineering Laboratory provides electronic, computer, and related services in support of research projects. The year's work was dominated once again by the installation of new automated data acquisition and irrigation control systems. The new projects were located at the USDA Irrigated Desert Research Station in Brawley, CA; at Harris Farms near Coalinga, CA; at the UC Wolfskill Experimental Station at Winters, Ca; and the UC West Side Field Station near Five Points, CA.

Work continued on the Brawley project with the addition of field F3 to the irrigation control system. Four dataloggers were installed in the field to measure soil moisture sensors and were interfaced to the irrigation control datalogger to trigger irrigations automatically. A priming pump was installed and the pump panel was redesigned to provide automatic pump priming of the two irrigation pumps.

Evaporation pan systems were installed at Harris and Wolfskill to control irrigation and measure pressure and flow. The system at Harris was interfaced to a cellular transceiver for remote access. A phone line was provided for remote access of the Wolfskill system.

A Bowen Ratio system was setup at the West Side Field Station along with two ET gauges. Work was started on a system to control the irrigation of nine treatments on the 36 Plots field.

Datalogger programs were written and daily reports set up for the above systems. The automatic data system was upgraded with a faster computer and software updates. A paper was written for presentation at the 1992 ASAE Summer Meeting entitled, "Automated Centralized Data Acquisition and Control of Irrigation Management Systems". Other work included the setup and configuration of various computers, electronic and computer repairs, routine maintenance of field systems, and miscellaneous data processing.

The work load for the year was heavy. Help from student workers has improved. There are now twelve separate automated irrigation systems of varying compexities. More installations are planned for 1993.

RESEARCH SHOP

David R. Dettinger

The research shop provides machine shop service for the various projects at WMRL. Responsibilities include routine inspections and maintenance of vehicles and heavy equipment. Transportation of tractors and trencher to field locations, including Brawley, CA. Operating equipment, tractors, trencher and driving truck.

Some of the work performed this last year has included:

1. Construction of two large monolith containers.
2. Help with collection of monoliths.
3. Move equipment from airport shop and dispose of surplus.
4. Work at Parlier in preparation for move.
5. Help with installation of drip irrigated plots at Peach Avenue station.

At this time, construction of the new shop building has just been completed and should be in use soon. This new facility is much appreciated and will provide greater service.

PUBLIATIONS

MANUSCRIPT PUBLISHED IN 1992

Ayars, J.E. 1992. Water quality and drainage in the western United States. Corrugated Plastic Pipeline, the CPPA Newsletter, 4:3–4

Ayars, J.E. 1992. Relationship between contaminant loads and drain flows for drainage systems in western San Joaquin Valley, California. Final Report on contract B–57376, submitted to California Department of Water Resources. 78 pp.

Ayars, J.E., C.J. Phene, R.B. Hutmacher, G.E. Cardon, and D.A. Clark. 1992. Techniques for irrigation scheduling of subsurface drip irrigation. Proceedings of CIT/USDA–ARS Seminar on Subsurface Drip Irrigation: Theory, Practice and Application, Harris Ranch – 10/22/92 – Coalinga, California. pp. 21.

Ayars, J.E., C.J. Phene, H.I. Nightingale, R.A. Schoneman, and B. Meso. 1992. Impact of subsurface drip on groundwater quality. ASAE 1992 Inter' Winter Meeting, December 15–18, 1992, Nashville, TN, Paper #922573 18 pp.

Ayars, J.E., C.J. Phene, R.A. Schoneman, H.I. Nightingale, B. Meso, and F. Dale. 1992. Subsurface drip irrigation of tomato and cotton in the presence of a water table. ASAE 1992 International Summer Meeting, June 21–24, Charlotte, N.C. Paper # 922059. 27 pp.

Ayars, J.E. and R.A. Schoneman. 1992. Drainage effects on water quality in irrigated lands in Drainage and Water Table Control Proceedings of The Sixth International Drainage Symposium ASAE Publication 13–92. 13–15 December, Nashville, Tennessee pp. 371–378.

Banuelos, G.S., G. Cardon, T. Pflaum, and S. Akohoue. 1992. Comparison of dry ashing and wet acid digestion on the determination of boron in plant tissue. Communication in Soil Science and Plant Analysis, 23(17–20):2383–2397

Banuelos, G.S., R. Mead, D. Meek, and C.J. Phene. 1992. Relations between phorphorus in drip irrigation water and selenium uptake by wild mustard. Journal of Environmental Science and Health. 27:283–297.

Banuelos, G.S., R. Mead, L. Wu, P. Beuselinck, and S. Akohoue. 1992. Differential selenium accumulation among forage plant species grown in soils amended with selenium–enriched plant tissue. J. Soil and Water Cons. 47(4):338–342.

Bañuelos, G.S., S. Tebbets, R. Perry, J.E. Duffus, and P. Vail. 1992. The potential of non–native selenium accumulating mustard plants as host for beet leafhopper and beet curly top virus. Southwestern Entomologist Scientific Note. 17(1):73–75.

Bar Yosef, B., C.J. Phene, B. Sagiv, T. Markovitch, and I. Levkovitch. 1992. Positive response in field crop yields to subsurface drip irrigation and fertilization via the water. Hassadeh #2519(5):

Ben–Asher, J., C.J. Phene and A. Kinarti. 1992. Canopy temperature to assess daily evapotranspiration and management of high frequency drip irrigation systems. Agricultural Water Management, 22:379–390.

Cardon, G.E., D.A. Clark, and c.J. Phene. 1992. Irrigation feedback control system for use with subsurface drip irrigation systems. Proceedings of CIT/USDA–ARS Seminar on Subsurface Drip Irrigation: Theory, Practice and Application, Harris Ranch – 10/22/92 – Coalinga, California. pp. 7.

Center for Irrigation Technology and Water Management Research Laboratory. 1992. Subsur–face drip irrigation; theory, practices and applica–tion, October 22, 1992, Coalinga, CA. CATI Publication Number 921001

Clark, D.A. and C.J. Phene. 1992. Automated centralized data acquisition and control of irrigation management systems. ASAE 1992 Inter' Summer Meeting, June 21–24, 1992, Charlotte, NC, Paper #923021, 11 pp.

Davis, K.R. 1992. Subsurface drip irrigation: Management for longevity. Proceedings of CIT/USDA–ARS Seminar on Subsurface Drip Irrigation: Theory, Practice and Application, Harris Ranch – 10/22/92 – Coalinga, California. pp. 4.

Detar, W.R., C.J. Phene, and D.A. Clark. 1992. Subsurface drip irrigation compared to furrow irrigation of cotton. 1992 Proc. Beltwide Cotton Conference. 1:494–495.

Hutmacher, R.B., C.J. Phene, R.M. Mead, D. Clark, P. Shouse, S.S. Vail, R. Swain, M. van Genuchten, T. Donovan, and J. Jobes. 1992. Subsurface drip irrigation of alfalfa in the Imperial Valley. Proc. 22nd California/Arizona Alfalfa Symposium, Univ. of CA and Univ. of A Coop. Ext., December 9–10, 1992, Holtville, CA. 22:20–32.

Hutmacher, R.B., C.J. Phene, R.M. Mead, K.R. Davis, and S.S. Vail. 1992. Fertigation management with subsurface drip irrigation for efficient crop nutrient uptake. Proceedings of CIT/ USDA–ARS Seminar on Subsurface Drip Irrigation: Theory, Practice and Application, Harris Ranch – 10/22/92 – Coalinga, California. pp. 19.

Knoche, L. 1992. The incredible truth about subsur–face irrigation. Told by those who use it... Water Conservation News, October 1992.

Marani, A., G.E. Cardon, and C.J. Phene. 1992. CALGOS, a version of GOSSYM adapted for irrigated cotton. I. Drip irrigation, soil water transport and root growth. 1992 Proc. Beltwide Cotton Conference. 3:1352–1357.

Marani, A., C.J. Phene, and G.E. Cardon. 1992. CALGOS, a version of GOSSYM adapted for irrigated cotton. II. Leaf water potential and the effect of water stress. 1992 Proc. Beltwide Cotton Conference. 3:1358–1360.

Marani, A., C.J. Phene, and G.E. Cardon. 1992. CALGOS, a version of GOSSYM adapted for irrigated cotton. III. Leaf and boll growth routines. 1992 Proc. Beltwide Cotton Conference. 3:1361–1363.

Mcmullin, E. 1992. Gold down under. California Farmer. 275(3):6–7,38.

Mead, R.M., R.B. Hutmacher, and C.J. Phene. 1992. Subsurface drip irrigation of alfalfa. Proceedings of CIT/USDA–ARS Seminar on Subsurface Drip Irrigation: Theory, Practice and Application, Harris Ranch – 10/22/92 – Coalinga, California. pp. 3.

Phene, C.J. 1992. Maximizing productivity with subsurface drip irrigation. Proc. Leafy Veg. Conf., Monterey, CA. Sept 14–16, 1992. pp 2.

Phene, C.J., D.A. Clark, G.E. Cardon, and R.M. Mead. 1992. Soil matric potential sensor research and application. Chap. 14. In: Advances in Measurement of Soil Properties: Bringing Theory Into Practice. Soil Soc. of Amer. SSSA Special Publication no. 30. pp. 263–280.

Phene, C.J., W.R. DeTar, and D.A. Clark. 1992. SW–2409 Real time irrigation scheduling of cotton with an automated pan evaporation system. Applied Engineering in Agriculture. 8(6):787–793.

Phene, C.J., R.B. Hutmacher, and J.E. Ayars. 1992. Subsurface drip irrigation: Realizing the full potential. Proceedings of CIT/USDA–ARS Seminar on Subsurface Drip Irrigation: Theory, Practice and Application, Harris Ranch, 10/22/92, Coalinga, California. pp. 24.

Phene, C.J., R.B. Hutmacher, J.E. Ayars, K.R. Davis, R.M. Mead, R.A. Schoneman. 1992. Maximizing water use efficiency with subsurface drip irrigation. ASAE 1992 Inter' Summer Meeting, June 21–24, 1992, Charlotte, NC, Paper #922090, 29 pp.

Phene, C.J., R.B. Hutmacher, D.A. Clark, K.R. Davis, S.S. Vail, and T.J. Pflaum. 1992. Effects of irrigation management and mineral nutrition on productivity of tomatoes. EEC Workshop on Processing Tomatoes, Avignon, France, December 17, 1992. pp. 17–29.

Phene, C.J., R.B. Hutmacher, and K.R. Davis. 1992. Two hundred tons per hectare of processing tomatoes, can we reach it? Hortechnology Journal 2(1):16–22.

Phene, C.J., R.B. Hutmacher, and K.R. Davis. 1992. Subsurface drip irrigation: cotton does not need to be a high water user. 1992 Proc. Beltwide Cotton Conference. 1:489–493.

Phene, C.J., R. Yue, I–Pai Wu, J.E. Ayars, R.A. Schoneman, B. Meso. 1992. Distribution uniformity of subsurface drip irrigation systems. ASAE 1992 Inter' Winter Meeting, December 15–18, 1992, Nashville, TN, Paper #922569 14 pp.

Schoneman, R.A., H.I. Nightingale, and B. Varnell. 1992. Field installation at Britz Farms. Proceedings of CIT/USDA–ARS Seminar on Subsurface Drip Irrigation: Theory, Practice and Application, Harris Ranch – 10/22/92 – Coalinga, California. pp. 4

Schoneman, R.A., H.I. Nightingale, and B. Varnell. 1992. Subsurface Drip Installation. ASAE 1992 Inter' Winter Meeting, December 15–18, 1992, Nashville, TN, Paper #922552 5 pp.

Shackel, K.A., R.S. Johnson, C.K. Medawar, and C.J. Phene. 1992. Substantial errors in estimates of sap flow using the heat balance technique under field conditions. J. Amer. Soc. Hort. Sci. 117(2):351–356

Speiser, D.M., S.L. Abrahamson, G.S. Banuelos, and D.W. Ow. 1992. Brassica juncea produces a phytochelatin–cadminum–sulfide complex. Plant Physiol. 99:817–821.

Yue, R, C.J. Phene, F. Dale, J.E. Ayars, R.A. Schoneman, and B. Meso. 1992. Field uniformity of subsurface drip irrigation. Proceedings of CIT/USDA–ARS Seminar on Subsurface Drip Irrigation: Theory, Practice and Application, Harris Ranch – 10/22/92 – Coalinga, California. pp. 3

PAPERS FOR PUBLICATION IN 1993

Ayars, J.E. 1993. Drainage load–flow relationship in arid irrigated areas. Submitted to Transaction ASAE.

Ayars, J.E. 1993. Improved water management in the riverland of South Australia. Report to South Australian Department of Agriculture. 65 pp.

Ayars, J.E. and R.B. Hutamcher. 1993. Managing soil salinity under micro–irrigation with saline water. Proceedings of Workshop on Micro Irrigation Worldwide, 15th International Congress on Irrigation and Drainage, The Hague, The Netherlands, Sept. 2.

Ayars, J.E., R.B. Hutmacher, C.J. Phene, and R.A. Schoneman. 1993. Managing irrigation in the presence of groundwater, Management of Irrigation and Drainage Systems: Integrated Perspectives. Proceedings 1993 National Conference on Irrigation and Drainage Engineering, ASCE. Park City, Utah. pp. 723–730.

Ayars, J.E. and C.J. Phene. 1993. Impact of improved irrigation on groundwater quality. Proceed–ings of "Agricultural Research to Protect Water Quality" Conference, Soil and Water Conservation Society, Minneapolis, Minn. Feburary 22–24, 1993.

Ayars, J.E., C.J. Phene, R.B. Hutmacher, G.E. Cardòn, and D.A. Clark. 1993. Techniques for irrigation scheduling of subsurface drip irrigation. Subsurface Drip Irrigation Theory, Practices and Application, CATI Publication 921001, Center for Irrigation Technology, Fresno, California. pp 43–56.

Ayars J.E. and K.K. Tanji. 1993. Effects of drainage on water quality in arid and semi–arid irrigation lands, Chapter 25 in ASA Drainage Monograph, American Society of Agronomy.

Banuelos, G.S. 1993. Bio–remediation of seleniferous soils in central California with selenium accumulating crops. Proc. of Food Systems and the Environment Conference, August 11, 1993. pp. 25–33.

Banuelos, G.S., S. Akohoue, S. Zambruski, S. Downey, R. Mead, and M. Banghoo. 1993. Boron and selenium removal in boron–laden soils by kenaf. Proc. of III International Kenaf Conf. pp. 84–91.

Banuelos, G.S., S. Akohoue, S. Zambruski, and R.M. Mead. 1993. Trace element composition of different plant species used for remediation of boron–laden soils. Accepted 5, 1993. Plant and Soil.

Banuelos, G.S., G. Cardon, B. Mackey, J. Ben–Asher, L. Wu, and P. Beuselinck. 1993. Boron and selenium removal in boron–laden soil by birdsfoot trefoil. Accepted April 14, 1993. Lotus Letters. Vol. 22.

Banuelos, G.S., G. Cardon, B. Mackey, J. Ben–Asher, L. Wu, P. Beuselinck, S. Akohoue, and S. Zambrzuski. 1993. Boron and selenium removal in boron laden soils by four sprinkler irrigated plant species. Accepted January 18, 1993. J. Envir. Qual.

Banuelos, G.S., G.E. Cardon, C.J. Phene, L. Wu, S. Akohoue and S. Zambrzuski. 1993. Soil boron and selenium removal by three plant species. Plant and Soil, 148: 253–263, 1993.

Bañuelos, G.S., R.M. Mead, and G.J. Hoffman. 1993. Accumulation of selenium in wild mustard irrigated with agricultural effluent. Agriculture, Environ. & Ecosystem. 43:119–126.

Ben–Asher, J. and C.J. Phene. 1993. The effect of surface drip irrigation on soil water regime evaporation and transpiration. Proceedings, Agritech 93, 6th International Conference on Irrigation, Tel–Aviv, Israel, May 3–4, 1993, pp. 35–42.

Cardon, G.E., C.J. Phene, and D.A. Clark. 1993. Soil matric potential sensor calibration: Physical equipment and statistical data processing methods. Applied Engineering in Agriculture, March 1993, 9(2):213–219. ASAE Conference Proceedings.

Detar, W.R., C.J. Phene, D.A. Clark, and T.A. Kerby. 1993. Comparison of water use and yields of Acala and Pima cottons for subsurface drip vs. furrow irrigation. Proc. Beltwide Cotton Conf., January 11–14, 1993, New Orleans, LA. pp. 540–541.

Hutmacher, R.B., C.J. Phene, K.R. Davis, and T.A. Kerby. 1993. Acala and Pima cotton responses to subsurface drip irrigation: Water use, plant water relations, yield. Proc. Beltwide Cotton Conf., January 11–14, 1993, New Orleans, LA. pp. 1221–1224.

Marani, A., R.B. Hutmacher and C.J. Phene. 1993. Validation of CALGOS simulation of leaf water potential in drip–irrigated cotton. Proc. Beltwide Cotton Conf., January 11–14, 1993, New Orleans, LA. pp. 1225–1228.

Phene, C.J. 1993. Potential of subsurface drip irrigation. Proceeding SCS Central Coast Microirrigtion Workshop and Tradeshow, October 21, Santa Maria, CA. (In progress)

Phene, C.J., D.A. Bucks, R.B. Hutmacher, and J.E. Ayars. 1993. Research successes, applications and needs of subsurface drip irrigation. Proceedings of ICID Meeting, La Hague, Netherlands, Aug. 30 – Sept. 11, 1993. (In Press)

Phene, C.J., K.R. Davis, R.B. Hutmacher, R.M. Mead, J.E. Ayars and R.A. Schoneman. 1993. Maximizing Water-Use Efficiency with Subsurface Drip Irrigation. Irrigation Journal, April 1993, pp. 8, 11–13.

Phene, C.J., R.B. Hutmacher, J.E. Ayars and J. Ben-Asher. 1993. Subsurface drip irrigation, a BMP for controlling drainage outflow and reducing ground-water contamination. *In:* Environmental Impact of Agricultural Practices and Agrichemicals. Y. Eckstein and A. Zaporozec (eds.), Water Environment Federation, Alexandria, VA. pp. 51–69.

Phene, C.J., R.B. Hutmacher, K.R. Davis, S.S. Vail, and T.J. Pflaum. 1993. Effects of irrigation management and mineral nutrition on productivity of tomatoes. Tomato News, January 1993. pp. 18–29.

Phene, C.J., R. Yue, I. Wu, J.E. Ayars, R.A. Schoneman, and B. Meso. 1993. Distribution uniformity of subsurface drip irrigation systems. Applied Engineering (in review)

Vogt, W. 1993. Drip-Irrigated Alfalfa: Higher yields, less water. Hay and Forage Grower, March 1993, pp. 26, 31.